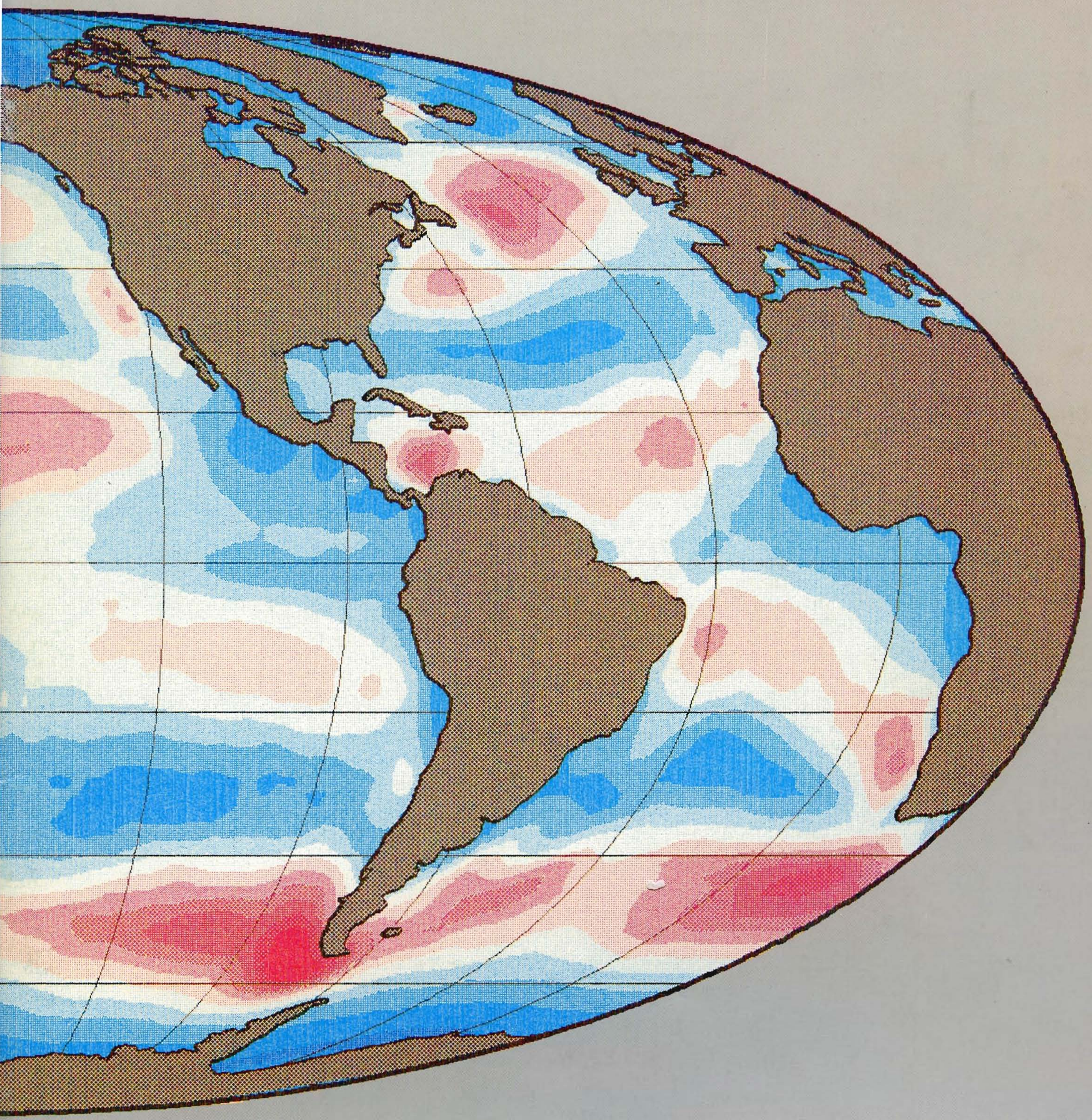
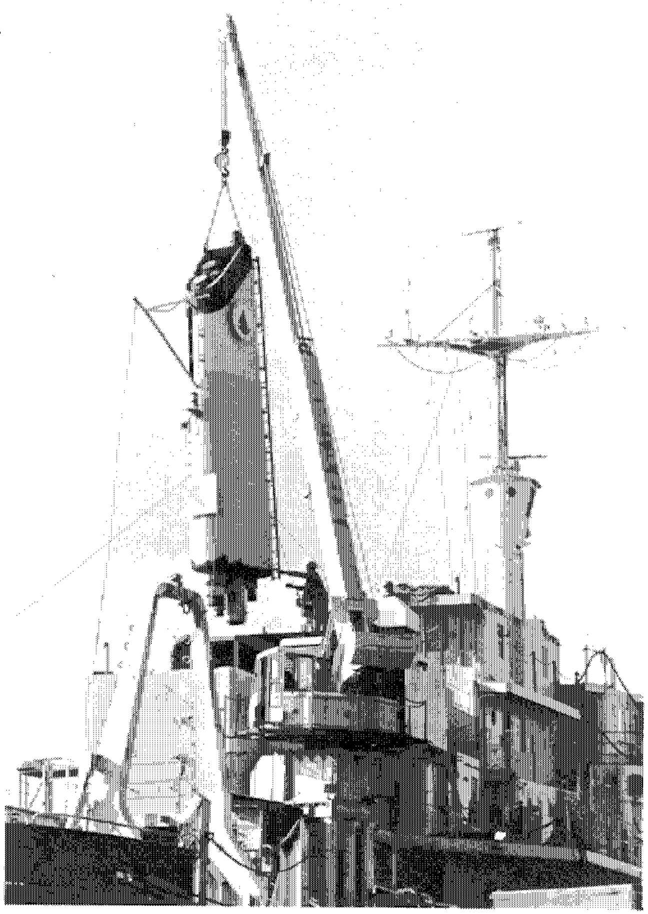
Woods Hole Oceanographic Institution

Annual Report 1983

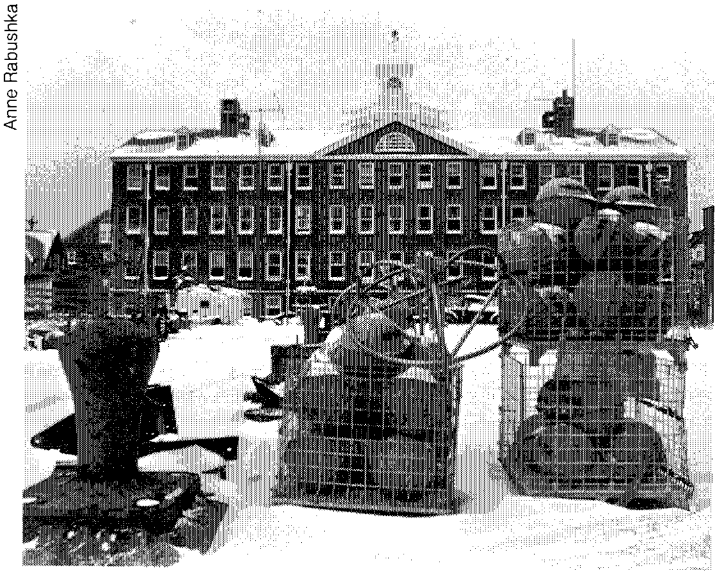


Vicky Cullen



Shelley Lauzon

Anne Rabushka



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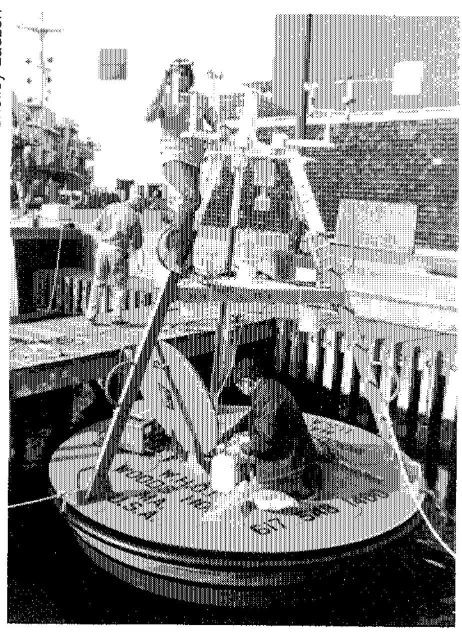

Top left: The stack is moved forward on *Atlantis II* in January 1983 to allow construction of the *Alvin* deck hangar.Top right: Channing Hilliard of the Information Processing Center prepares a color computer plot. Left: Craig Marquette (top) and Joe Poirier repair a LOTUS buoy. Above: Bigelow Laboratory from the Iselin mall.

Contents

Woods Hole, MA 02543
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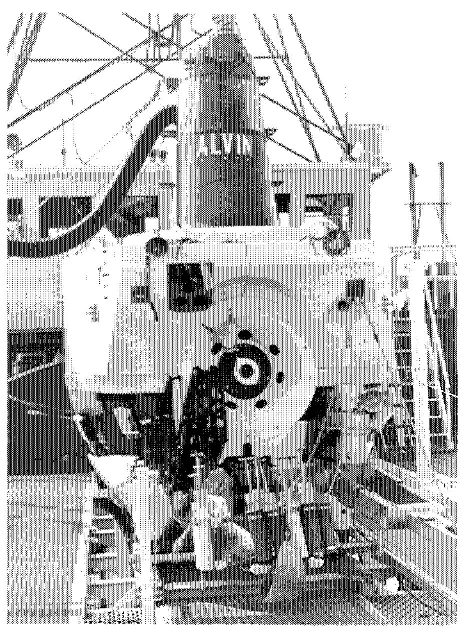
About the cover: The color computer image of global annual wind stress, generated from a computer tape by the Information Processing Center, was described in a July 1983 article in the *Journal of Physical Oceanography* by Sol Hellerman and Mel Rosenstein of the Geophysical Fluid Dynamics Laboratory at Princeton University, who provided the tape to Associate Scientist Mel Briscoe. The data represent more than 100 years of measurements from ships around the world. The brightest red areas indicate winds averaging more than 25 miles per hour on a yearly basis, while the darkest blue represents relatively no wind to about 6 miles per hour on an annual average. Mel reports that results from the LOTUS site, described in his article on page 22, show monthly variations in internal wave energy similar to the monthly changes in this global stress pattern. He notes, however, that the LOTUS site is not representative of world conditions and suggests that other sites be studied to better understand the link between surface wind and internal wave motion.

Annual Report 1983:
Shelley Lauzon, *Editor*
Kim Halliday, *Design Concept*
Reynolds-DeWalt Printing, Inc., *Printer*
Typesetting Service Corp., *Typographer*

Vicky Cullen

The Paul M. Fye Laboratory, dedicated 24 June 1983, on the Quissett Campus.



Shelley Lauzon

DSRV *Alvin* aboard R/V *Lulu* following the sub's annual overhaul and conversion for the new lift system on R/V *Atlantis II*.

Director's Comments

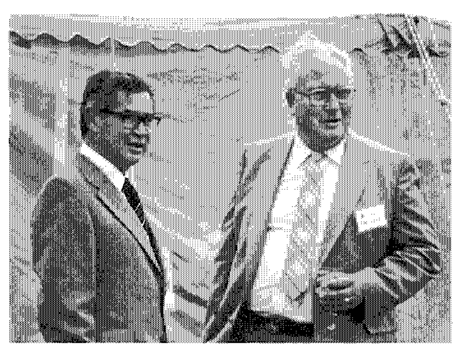
Historically our study of the oceans has attempted to encompass events at the local and global scales. Our predecessors went from collecting near shore to the deep-sea studies of the Challenger Expedition, from the Cape Cod salt marsh to North Atlantic circulation. In recent years we have focused on intermediate scales such as the Gulf Stream Rings. Now, once again, we are looking to global-scale events. What do we want to know scientifically? What do we need to know in a social context?

We talk about the ocean climate, partly by analogy with our atmospheric climate, but mainly in terms of the close relation of atmosphere and ocean. That analogy is relevant in terms of what we need to know. The regular cycles, diurnal or seasonal, clearly must be understood, but it is the departures from these average patterns that are critical for our social systems. We have learned to make some predictions about our weather and we know the limits to such predictions – about 10 days. Thus, we can separate weather from climate and realize that for the latter we shall need different concepts – concepts which must include the oceans as a central element. Our historical records show not only the year-to-year variability, but the longer term trends such as little ice ages. The recent increases in atmospheric CO_2 and the potential "greenhouse effect" are realities in the sense that there is general agreement about some atmospheric temperature increase. However, there is less agreement about the magnitude of this effect and, especially, time scales on which it may occur. The critical factor is the role of the oceans. We believe that the oceans have absorbed about half the excess CO_2, but there is still argument about the specific mechanisms, particularly on the longer term interactions between ocean circulation and atmospheric temperature and winds. How will changes in the ocean circulation affect the atmosphere and how is CO_2 involved? The ocean, because of its great heat capacity, absorbs much of the short term diurnal or seasonal temperature cycles and so ameliorates not only the local coastal climates, but the global system. This damping effect of the ocean is essential for the habitability of the land. But the tremendous capacity of the ocean to absorb heat means that the ocean can feed back variations at longer time scales. Thus, in a sense, we may pay for the short term smoothing through long term trends. These questions stress the need for a comprehensive view of the world's oceans as a dynamic system subject to change in its chemical and biological cycles, particularly at longer decadal time scales.

There is a further timely reason to consider these questions. We now have new technologies which enable us to take such a global view. Remote sensing by satellites and by ocean acoustics can play a crucial role because they enable us to cover scales from days to decades, from kilometers to the whole ocean. Other new developments – unmanned vehicles, long term moorings, subsurface drifters – will complement these synoptic methods. We look to these innovations, many of them coming from fields outside oceanography, to provide the data we need at these largest scales. Can all these elements be put together in a coherent scheme? This is the single most important question facing the oceanographic community today. The answer is not clear. There are many immediate or near-term issues concerning waste disposal, overfishing, and mineral rights. Such matters have pressing implications for state and federal legislation, while the concerns over climate at the global scale do not come within any particular jurisdiction. At the level of policy and social issues, how do we assess priorities? The implications of changing climate is, possibly, the greatest challenge we face and relevant to many other issues such as population distribution and food supply. It is less cataclysmic than nuclear war, but as portentous for human habitability. The time scales are decades, rather than hours, yet there is an immediate need for understanding these phenomena in order to take rational action.

John H. Steele
Director

Shelley Lauzon



Above: Director John H. Steele and Governor Michael S. Dukakis during the Governor's visit 12 August. Left: Enjoying a Woods Hole event with Associate Russell Babcock.

Areas of Interest

Biology

The broad aim of biological oceanographers is to study the temporal and spatial distributions of populations of marine organisms and their interactions with each other and their environment. The work is predominantly ecological in its attempts to provide the basic information required to understand how the ocean works biologically. Among the specific research interests of Institution biologists are microbiology, biochemistry, planktonology, benthic biology, physiology, biogeochemistry, animal behavior, and aquaculture. Work on marine pollution includes research on the effects of drilling muds and hydrocarbons and the biochemical responses of animals to these pollutants. The "patchy" distribution of many marine animals is under investigation as are the physiological adaptations of deep sea organisms to sparseness of food, low temperatures, high pressures, and deep sea thermal vents. Answers to questions about the food supply in the oceans are sought in studies of particles falling from the surface waters through the water column to the bottom of the sea, in studies of upwelling areas, through investigations of sulfur oxidizing organisms in the deep sea and shallow coastal ponds, and in laboratory experiments that complement field investigations. The uses of sound by marine mammals, mechanisms of fish swimming and gill ventilation, and the behavior of large marine animals followed by tagging are being studied. Other work concentrates on salt marsh ecology and conservation, nutrient cycling in coastal waters, and on aquaculture and waste water recycling. The symbiotic relationships between marine microbes and other organisms (including wood-borers) are a new focus. Gelatinous organisms of the plankton (salps, ctenophores, etc.) are being studied with new techniques that finally allow us to properly evaluate the roles of these organisms in the oceans.

Chemistry

Chemical oceanographers are concerned with the composition of the ocean environment. They seek to understand the processes that have brought seawater and sediments to their present composition and that contribute to the observed variability. They also seek understanding of the extent to which the environment may be changed by both natural and man-made phenomena operating on a variety of time scales. Input from rivers and reactions at the air-sea, seawater-sediment boundaries and seawater-volcanic rock interaction at spreading centers are under investigation as chemists consider the processes taking place at major ocean boundaries. Some critical questions in chemical oceanography revolve around the vertical transport and transformations in particles as they fall from the surface waters to the bottom of the water column. The photochemistry of the surface ocean and the marine atmosphere is critical to our understanding of the global sources and sinks for many gases. The genesis and composition of the oceanic crust and its interaction with seawater is important to a general understanding of the oceanic system. Studies concerning the interstitial water chemistry of deep sea sediments help us to better understand the diffusive flux of ions between sediments and the oceans. Work on the fluxes of organic carbon includes determination of the amount of organic carbon produced in surface waters, the distribution, nature, and biogeochemistry of specific organic compounds in the marine environment, and studies of processes responsible for formation and diagenesis of organic matter in sediments. While studying radioactive isotopes in the ocean, whether as a natural occurrence or as a form of pollution, chemists are also finding the known decay rates of the isotopes useful as indicators for studying rates of water circulation, the in situ rates of chemical processes in the sea, and rates of biological and chemical processes that change the composition of seawater. Stable isotopic studies in rocks can be used as geochemical and petrological indicators of large scale terrestrial mantle processes.

Geology and Geophysics

Marine geologists and geophysicists study the processes which form and affect the earth beneath the sea, as reflected in its underlying structure and composition. The sedimentary and volcanic material of the seabed is investigated by direct sampling and remote observation. Coring, dredging, or drilling techniques are commonly used to obtain samples, which are further classified in the laboratory by petrological descriptions, geochemical analyses, and measurement of physical properties. Geophysical methods include the fields of seismology, gravity, magnetism, and geothermics. The establishment of plate tectonics as the primary kinetic process creating and shaping ocean basins has focused attention at the boundaries where plates interact. At divergent plate boundaries, or mid-ocean ridges, the processes which bring up hot materials to create ocean crust and lithosphere are studied in detail. Investigations of rifted continental margins of different geological ages are important to understand how continental plates initially break apart. Finally, subduction of oceanic lithosphere beneath either continental or other oceanic lithosphere is a process which is ultimately associated with the creation of deep sea trenches and back-arc basins, accompanied by the important geological phenomena of earthquake belts and volcanic island arcs. Research is actively pursued on processes of particulate flux in the ocean ('marine snow'), carbonate and silicate dissolution, and other phenomena relevant to the transport of biogenic material to the sea floor. The results are essential to a better understanding of the fossil record, which in combination with studies of its oxygen isotopic variation reveal changes in climate and ocean environment over periods of thousands to millions of years. The study of the dynamics of sediment distribution on the ocean floor is important to deciphering the fossil record and interpreting sea floor morphology. Marine geologists also study near-shore and shallower regions such as continental shelves and coasts where earth, ocean, and atmosphere dynamically interact to produce complex and rapidly-changing morphology.

Ocean Engineering

The field of ocean engineering is a complex hybrid of many of the classical engineering disciplines such as electrical, mechanical, civil, chemical, and marine engineering. Its purview is broad and interdisciplinary. Ocean engineers conduct research and design instrumentation in almost every field of oceanography. Mechanical, electrical, acoustical, chemical, optical, civil, marine, and ocean engineering talents are used to develop techniques for measuring oceanic processes and for answering basic scientific questions about the marine environment. Measurement programs span ocean time scales of years to milliseconds and ocean space scales of kilometers to millimeters. Electronic data handling and processing circuits using microprocessors are developed for these programs. Instrument housings and anchoring and mooring systems are designed, fabricated, and deployed at sea. Acoustic techniques are applied to measurement problems. Manned and unmanned deep submersible systems are engineered for search and discovery. Techniques for using the earth orbiting satellite as an observational tool are being developed together with image enhancement and image processing algorithms. Information processing, whether applied to acoustic systems, satellite images, geophysical time series or general data reduction is the primary concern of a large segment of the department. Research is conducted in hydrodynamics, signal processing theory, applied mathematics, acoustic tomography and propagation, deep submergence engineering, arctic acoustics, coastal processes and benthic currents, and instrumentation techniques. Programs in mooring materials and design, electronic and microprocessor applications, optical measurement, and remote observation and sampling support these and other scientific projects throughout the Institution. The technological sophistication of modern ocean science demands the application of special engineering knowledge and skills. The solution of challenging problems requires creative combinations of wide ranging ocean engineering principles.

Physical Oceanography

Physical oceanography is the study of the physics of the ocean. Its central goal is to describe and explain the complex motion of the ocean which occurs over a very wide range of scales. Variations of the temperature and salinity, the driving effects of the winds, the rotation of the earth, and the pull of the sun and the moon all contribute to these motions. There are grand persistent currents like the Gulf Stream, and there are transient waves and eddies of almost all sizes and speeds, from high frequency acoustic and surface gravity waves, to slower internal gravity waves beneath the sea surface. Large regions of the oceans are dominated by the mesoscale eddying vortical patterns of flow that display visual and dynamic similarity to atmospheric weather patterns. As in the atmosphere, relatively intense frontal systems exist. Important mixing and stirring of the ocean is accomplished by a variety of physical processes, some of great subtlety like the phenomenon of "salt fingers" whose sizes are on the centimeter scale. Important scientific questions also arise in considering the interaction of the ocean with the atmosphere. The ocean and the atmosphere drive each other in an as yet poorly understood way: exchanges of energy between the air and sea are important in determining the climate of both the atmosphere and the oceans. Physical processes in coastal regions are strongly affected by atmospheric forcing and bottom topography, and the current and wave systems in this complicated region are of vast importance to the local climate and ecology. Physical oceanography staff members are involved in experimental, theoretical, laboratory, and numerical investigations of many parts of the system of oceanic motions. Small programs and large international projects are underway, and multidisciplinary efforts are increasing. All of these studies have the ultimate goal of understanding the structure and movement of the world's oceans, the interaction of the sea with its boundaries, and the physical role of the ocean in relation to other branches of oceanography. Physical oceanographers come to the subject with a variety of backgrounds: mathematics, physics, engineering, computers, and chemistry. The mix of interests provides a broad approach to the equally broad range of problems in the ocean.

Marine Policy & Ocean Management

The Marine Policy and Ocean Management Center is an interdisciplinary research program; its structure provides an opportunity for scholars to conduct research regarding the problems and opportunities generated by our increasing use of the ocean. Evaluating and suggesting appropriate policies and management strategies to deal with the issues of marine resource development, utilization, and protection are complex tasks, often requiring the data and skills of both natural/physical scientists and social scientists. The three main objectives of the Marine Policy Center are: to provide opportunities for interdisciplinary application of natural science, technology, and social science to marine policy problems; to research, evaluate, and convey the information necessary for the development or modification of local, national, and international ocean policy; and to provide support and experience to Research Fellows interested in marine policy issues. The professional research staff conducts studies on a wide range of policy issues, aided by a competent support staff. In addition, the Center sponsors seminars, conferences, and lectures on marine policy issues. Most of the present research activities at the Center are grouped within several general thematic areas: 1) cooperative international marine affairs projects; 2) Law of the Sea issues and implications for U.S. marine policy; 3) marine minerals and mining studies; 4) coastal and fisheries management issues; and 5) the interaction of science and policy. The Marine Policy Center offers Research Fellowships to professionals in the social sciences, law, or natural sciences to apply their training to problems that involve the use of the oceans. Thus far, over 90 Fellows trained in such fields as law, economics, anthropology, political science, engineering, marine science, mathematics and geography have taken part in the program.

Reports on Research

The continued progress of ocean sciences is dependent upon many factors. The most important of these are a continued input of bright young minds to stimulate new thinking and challenge accepted wisdom, a steady flow of funds sufficient to accomplish key tasks, and a continual introduction of new technology that allows us to view the ocean in different perspectives. If the flow of any of these critical ingredients were to dry up, our science would stagnate and wither from a lack of vitality and purpose. In this report we choose to present highlights of some of the technological developments that have given us new insights into ocean phenomena or have great potential for future discoveries. As with past reports, space does not allow for a complete portrayal of all of the innovations having important impacts on our work.

In common with many disciplines, oceanography is dependent on the analytical tools of the laboratory and office. Sensitive and precise measurements of samples of water, animals, or sediments play a major role in many of our projects, particularly those of the Chemistry and Biology Departments. Chemicals produced by organisms, including man, may be used to follow the pathways of many ocean processes. However, the most useful of these "tracers" are invariably present at exceedingly low concentrations. It is generally true that the precision and sensitivity of measurement demanded by ocean sciences are exceeded in no other areas. The article by Nelson Frew and Bill Jenkins provides a good example of one class of instrumentation, mass spectrometers, that are now essential to our work. The authors point out that, using a mass spectrometer built at WHOI, we can measure as few as 3,000 atoms of helium gas. This achievement is put into perspective if one considers that an ounce of helium gas contains over 5,000 trillion trillion atoms.

However, unlike many disciplines, oceanography is highly dependent upon instruments and facilities to observe and measure in situ phenomena, often in a turbulent and hostile environment. In addition, the earth's crust beneath the ocean holds many secrets that are slowly being revealed as we develop the capabilities to probe the crust with geophysical tools and drill strings. Over the last decade the drilling ship *Glomar Challenger* has provided limited access to this new world. Among many achievements, ocean drilling has already proven the concepts of plate tectonics and provided us with insights into global climatic changes during the ice ages. In 1985 a new phase of ocean drilling will start; its significance is described in the article by Dick Von Herzen.

Perhaps the best known of our "ocean facilities" is the research submersible *Alvin*. Since the development of a deep-sea navigation system several years ago, *Alvin* has become a premier tool for seafloor studies. The recent conversion of R/V *Atlantis II* to act as the *Alvin* mother ship, described in the article by George Grice, has greatly increased the worldwide scope of *Alvin* programs. The breadth of *Alvin* science is covered in articles by Fred Grassle, Holger Jannasch, and Mike Mottl.

Although *Alvin* will continue to be the principal vehicle allowing us to experiment at the sea floor for the next several years, programs are already underway to extend our submersible science capabilities principally by remote unmanned vehicles incorporating modern developments in minicomputers, robotics, and digital television. The article by Bob Ballard, Dana Yoerger, and Ken Stewart outlines some of the exciting possibilities that may be offered to future students of the sea bottom.

Any traveler knows that one of the most important sources of information about the places he visits is a good map. This is no less true of oceanographers, and it is perhaps surprising that only in the last two years has the ocean science community had the ability to produce accurate detailed maps of the sea floor. The introduction of high resolution, multibeam echo sounding techniques and their impact is described by Brian Tucholke and Ann Martin.

One of the most basic tools for observing the motion of the worlds' oceans is the deep sea mooring equipped with current meters and other instruments. The Woods Hole Oceanographic Institution has pioneered the use of deep sea moorings for studies of ocean currents. The WHOI Buoy Group is world renowned for its expertise in the successful deployment and recovery of moorings. During the early days of mooring deployments in the late 1960s, recovery rates of 50 percent or less for periods of two to three months were not uncommon. Today mooring recovery rates are in excess of 99 percent for deployment periods of up to two years. Some of the technology involved is described by Bob Walden and Henri Berteaux, while the article by Mel Briscoe gives an example of the kinds of information obtained by reliable in situ moored instrumentation.

The increased data recovery that has been possible with long mooring deployments has had one disadvantage. Three or more years may elapse from the time a scientist plans an experiment to the time the data is available for study. The tedium of this wait will be eliminated and several direct advantages for the science will result from the program described by Bob Chase which will provide us with the capability of transmitting data, shortly after it is obtained from moorings and floats in remote areas, via satellite to shore stations.

The final article illustrates the kind of instrument development projects that WHOI scientists often need to pursue to answer specific questions that they raise concerning ocean phenomena. Seismic studies of the events beneath the ocean are being helped greatly by hydrophone systems located on the sea floor rather than on ships some 4-5 kilometers (2-3 miles) above the sea floor. Mike Purdy describes some of our recent progress in this area.

Derek W. Spencer
Associate Director for Research

Mass Spectrometry in Oceanography

Nelson M. Frew and William J. Jenkins

Studying the chemistry, biology, geology and physics of the sea often requires the precise measurement of extraordinarily minute quantities of substances. These measurements involve either the isotopes (atoms of the same element but differing masses) or separation and detection of rare and complex compounds. One of the most powerful and useful tools for these measurements is the mass spectrometer, which detects very small amounts of materials by separating charged fragments of compounds, or individual atoms, by their mass.

Although separation by mass is not a new concept, recent technological advances have dramatically expanded our scientific horizons. Computers allow sophisticated data collection and synthesis, and rapid automated analysis. Improvements in electronics and vacuum technology have also been important, but substantial advances in the instruments themselves – higher sensitivity, resolution and stability – have opened many analytical doors.

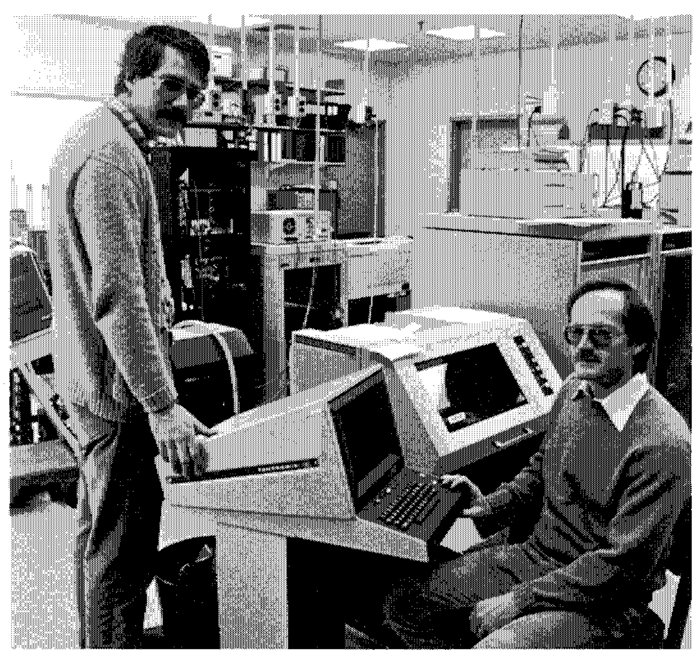
Three of the world's most sensitive and sophisticated helium isotope mass spectrometers were designed and constructed here at WHOI. The vacuum systems of the isotope mass spectrometers are all metal and can be "baked" to 400°C (700°F) to achieve vacuums of less than 10^{-11} atmospheres. Instrument control and monitoring is achieved with minicomputers which maintain electric and magnetic fields, monitor vacuum, control the cyrogenics, operate valves and collect data. Each instrument has its own computer, and each computer has several programs operating simultaneously on these tasks. One mass spectrometer has an additional, smaller mass spectrometer as part of its system, pre-analyzing the samples for size and purity. This auxiliary instrument is also controlled by the main spectrometer's computer.

A major improvement in sample processing came with the use of cyrogenic systems. Each spectrometer has "traps" or filters cooled by a refrigerator which uses helium rather than freon as a working fluid. These traps are operated to temperatures below 10°K (-440°F) under computer control, allowing extremely good sample purification. The result is the ability to measure exceptionally small quantities of gases with unparalled accuracy. As little as 3,000 atoms of ^3He (helium-3) can be measured, and the amount of helium in as little as one millionth of a cubic centimeter (cc) of air can be detected.

These instruments are used for a variety of scientific problems. Determination of radioactive tritium in seawater by the ingrowth of its daughter, ^3He, has given us the world's most sensitive and accurate measurement of that substance. We can measure tritium more than four times more precisely and to a level fifty times lower than any laboratory in the world! Such capability has enabled us to study the invasion of man-made tritium produced during earlier atmospheric nuclear weapons tests into new areas of the ocean. Combined with the precise measurement of the helium isotopic ratio, we can date water masses on time scales of months to years, and determine the rates of flow and mixing as well as biological and chemical reactions.

Measurement of helium isotopes and other noble gases in rocks, sediments, and hydrothermal systems is providing us with insights into geochemical fluxes in the solid earth and gives us clues about the earth's formation, evolution, and structure. Sensitivity, accuracy, and extreme purity of sample are required.

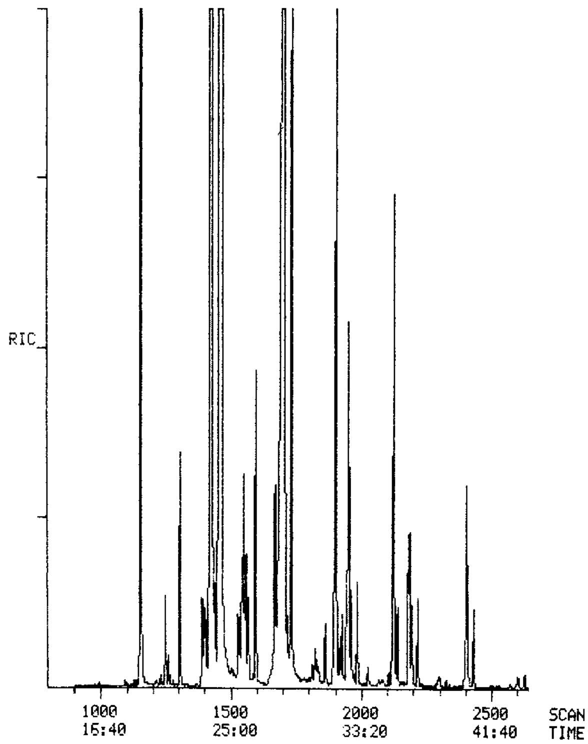
Other types of mass spectrometers at the Institution are specifically designed to determine the structure of complex organic molecules isolated from the environment and from organisms. Frequently these spectrometers are used in combination with the gas chromatograph, an instrument which separates complicated mixtures of organic compounds into individual pure components on the basis of their volatility and chemical reactivity. In recent years, WHOI researchers have acquired considerable expertise in state-of-the-art high resolution gas chromatography, with some of the best-equipped facilities in the marine community. Chromatographs using on-column injection and glass or fused silica capillary columns resolve hundreds of organic compounds in mixtures extracted from marine samples. Interfacing these two instruments provides a means for transferring pure components to the ion source of the mass spectrometer for structural identification. The combined gas chromatograph-mass spectrometer (GC-MS) is a powerful scientific tool, capable of identifying amounts of chemicals as small as one billionth of a gram.



Shelley Lauzon

Bill Jenkins (left) and Nelson Frew in the mass spectrometry facility at Fye Laboratory.

Reports on Research



Computer reconstructed gas chromatogram of a fatty acid mixture extracted from sediment trap material collected off the California coast.

The GC-MS produces tremendous quantities of data. The analysis of a single sample may easily generate 10 million bits of data. A computer is required to control the GC-MS system and to process and display this information. Using automated data reduction procedures, unknown chemical components are detected and their amounts are quantified. Components are automatically identified by comparing their mass spectra with a computerized library of more than 30,000 reference compounds compiled from laboratories throughout the world. A complete library search and comparison which provides the compound name, molecular weight, chemical formula, and statistical best fit information takes 30 seconds. Computer-automated procedures have substantially reduced the man-hours spent by investigators to process the raw data, leaving more time for interpretation of the results.

The analytical capabilities of combined GC-MS are utilized by WHOI scientists to study many aspects of the organic carbon cycle in the oceans. Carbon is fixed in the surface layers through photosynthetic production of organic matter, is released through excretion, grazing and predation, and eventually the death of organisms, to be partially recycled or remineralized in the surface layer. A significant fraction is transported out of the surface layer as particles or re-packaged as fecal material which generally sinks at higher rates to the sea floor, where further utilization by benthic organisms and incorporation into Recent sediments takes place. Chemical and biological processes continually alter the organic material at each stage. Subtle changes in chemical structure of functionality accompany these processes. By providing a detailed view of the molecular structures involved, mass spectrometers assist in determining specific sources of organic matter at different depths, the nature of the processes affecting it, and the time scales or rates at which these transformations occur. A common technique is to follow the fate of a specific compound from a particular type of organism through the major transport stages from surface production to sedimentary burial. Ideally, the compound, known as a biomarker, has a unique and recognizable structure which is preserved, but which may be altered in minor but informative ways. These changes, while subtle, often lead to clearly distinguishable mass spectral patterns, as happens, for example, in the reduction of a single double bond (addition of two hydrogen atoms) in an unsaturated fatty acid (see figure at left).

Mass spectrometers are used to study the chemical make-up of organisms and their responses to environmental conditions and stresses. Lipid composition, for example, may fluctuate significantly as a function of food source, temperature, and light intensity. Specialized biological systems such as the Galapagos Rift community are being examined for molecular clues to the mechanisms by which life is maintained in the absence of light and at high temperature and pressure. Other studies include research on the composition of marine aerosols, the dynamics of upwelling systems, and the origin of chemical fossils in ancient sediments. A variant of GC-MS known as pyrolysis GC-MS is used to investigate the nature of kerogen, a very complex mixture of somewhat inert substances making up the organic matter of more ancient sediments, and to assess the petroleum-bearing potential of shallow and deep-sea sediments.

Another application of mass spectrometry is the identification and quantitative measurement of anthropogenic organic pollutants, such as polynuclear aromatic hydrocarbons (PAH) and polychlorinated biphenyls (PCBs), their transfer into marine ecosystems and metabolism in marine organisms. The relative abundances of a homologous series of PAH, for example, may give clues to sources of fossil fuel inputs, whether from fuel spills or by airborne transport of combustion products. The complexity of environmental samples demands the sensitivity and high selectivity of the GC-MS as a detector of traces of individual chemicals in the presence of many interfering signals.

Other investigators are using mass spectrometers to measure subtle isotopic shifts in carbon and oxygen associated with biological activity, changes in water temperature, and ebb and flow of the global hydrographic cycle. These studies look at seasonal changes in the productivity of the sea and extend millions of years into the past. The mass spectrometer is a tool which spans all disciplines, from the study of fluid motion through biogeochemistry to geology. It has opened many doors in marine science and allowed us to study the inner workings of the sea.

Deep Sea Scientific Drilling: Results and Future Prospects

Richard P. Von Herzen

The latest phase of the Deep Sea Drilling Project (DSDP) ended in November 1983 after 15 years of nearly continuous research drilling in the deep oceans of the world. Drilling for the program was conducted primarily from the 400-foot-long *Glomar Challenger*, owned by Global Marine, Inc. and operated by the Scripps Institution of Oceanography on behalf of many of the major oceanographic institutions in this country and abroad. The program was truly international, with official participation of the United Kingdom, France, Federal Republic of Germany, Japan and, until recently, the Soviet Union, in addition to the United States. Marine scientists and geoscientists from many other countries have also participated in the drilling programs as well as in related scientific work, making this project one of the largest in oceanographic history.

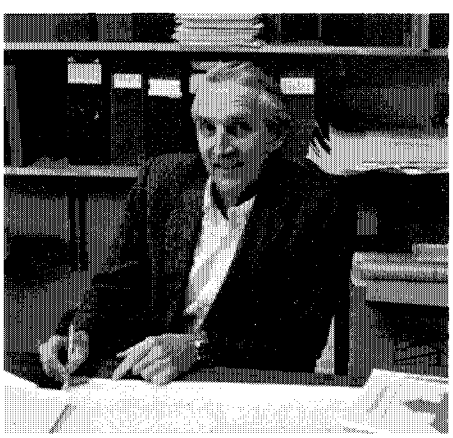
The scientific accomplishments of DSDP have been rather remarkable. Both the sedimentary deposits on the sea floor and the crustal rocks beneath it have been penetrated and cored. The *Glomar Challenger* made 96 cruises, each nearly two months long, during which 624 sites were occupied in all the world's oceans and almost 1,000 holes were drilled. The maximum water depth drilled was over 6,100 meters (20,000 feet) in the western Pacific, the maximum length drill string deployment was over 7,000 meters (23,000 feet) at this same location, and the maximum penetration of the drill string below the sea floor, 1,740 meters (5,700 feet), was made at site 398 in the eastern Atlantic. The greatest basement rock penetration, somewhat over 1 kilometer, was made in the Panama Basin of the eastern Pacific at site 504B; this unusually great drilling depth into hard basaltic rock was accomplished over three separate drilling cruises.

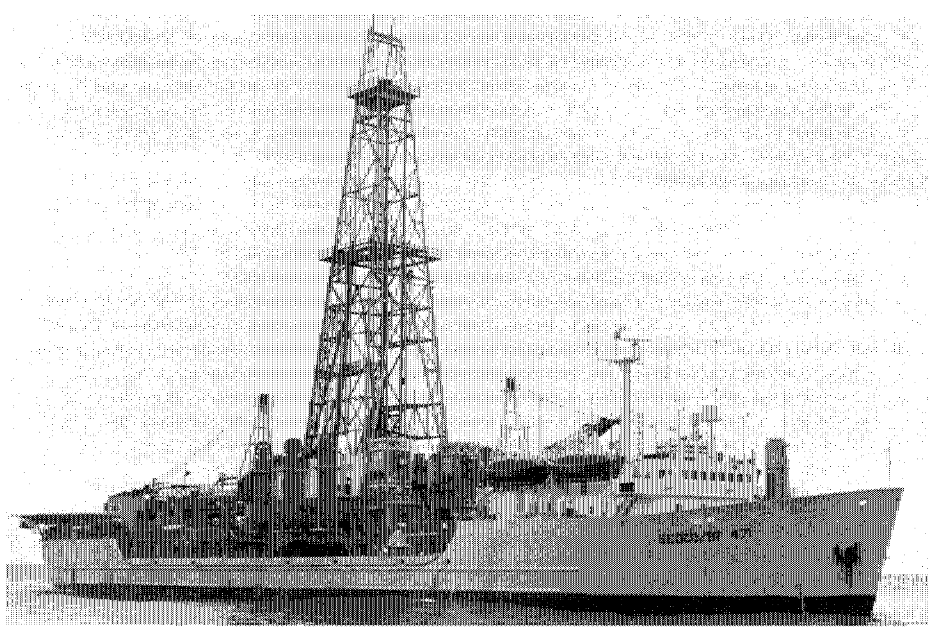
The many tens of thousands of meters of recovered core provide a wealth of scientific information. The sediments provide a clue to the past history of ocean and climate. Detailed and subtle variations of ocean variability back almost 150 million years ago have been documented. The structure and composition of the upper crust basement rock of the sea floor has been established at many locations. Although ocean floor basement rocks are relatively uniform compared to continents, subtle variations in petrology and chemistry reveal different magmatic and petrologic variations reflecting on the original composition and differentiation within the earth's interior. Both the sediments and crustal rocks show the effects of hydrothermal circulation at many locations, and its pervasive influence on the changes in mineralogy as well as on composition of ocean waters.

Planning is underway to continue the drilling program in early 1985. The successor to the Deep Sea Drilling Project, the Ocean Drilling Program (ODP), will utilize a different and technically advanced drilling vessel developed by industry and modified for scientific drilling needs, the 470-foot SEDCO/BP 471, a six-year-old ship jointly owned by Sedco, Inc. of Dallas, Texas, and the British Petroleum Company. The ship, which will probably be given a new name before starting its ODP career, has a 200-foot derrick and is not only larger than the *Glomar Challenger* but is able to carry and deploy a longer drill string (some 30,000 feet). It will have a riser capability, permitting core drilling in coastal waters up to 6,000 feet deep and protection against blowouts; a riser is a second pipe surrounding the main drill string which is connected to the drill ship at one end and

Right: The SEDCO/BP 471 will begin service for the Ocean Drilling Program in 1985. Below: Dick Von Herzen.

Shelley Lauzon





to the ocean floor at the other end to allow closed circulation of drilling fluids ("muds") and fluid pressure control in the drill hole. Its drilling capabilities represent a marked advance over those of its predecessor; a computer-controlled positioning system will enable the ship to maintain its position while drilling at depths up to 27,000 feet, and new electronic measuring equipment will make it possible to gather chemical and geophysical data during drilling that will enhance the value of the core samples obtained. The new ship will also have larger and better equipped laboratories and can accommodate 50 scientists and technicians, nearly twice as many as the *Glomar Challenger* could support.

New scientific objectives derived from a conference on scientific ocean drilling held in November 1981 are under consideration for the Ocean Drilling Program. Because of the increased size and better weather capabilities of the new ship, rougher sea conditions and higher latitudes can be tolerated for drilling. Some drilling in the Antarctic is anticipated, although floating ice will limit operations there. Ocean history as deciphered from the sediments at higher latitudes is especially important for models of past climate and air/sea interactions.

Secondly, the capability of a longer drill string will enable greater ocean depths to be considered, such as the oldest sea floor in the oceans as well as in deep sea trenches. Deeper penetration of the ocean crust and sediments should be possible. The drill string may even be tapered, with a larger diameter at the top for greater strength, or may be made up at least in part of aluminum rather than steel pipe.

Deeper penetration of the crust will enhance the scientific value of holes into which scientific instrumentation can be lowered. Instruments to determine the chemistry of rocks and pore waters as well as the seismic, thermal, magnetic and electrical properties of material surrounding the drill hole will help characterize the materials which comprise the ocean crust. In addition, development of wireline re-entry of boreholes from standard oceanographic vessels will allow such measurements in existing holes without the need of the costly drilling vessel.

A fourth consideration is the riser capability, which initially will not be available, to permit drilling deeper holes near the continental margins. The outer slope and continental rise, where very thick sediments (more than 10 kilometers, or 15 miles) are known to exist, may be drilled efficiently and safely.

Engineering developments are underway to provide an ability to drill directly into hard basement rocks on the sea floor without the relatively soft sediment cover normally used to stabilize the drill string. This capability will allow drilling on the geologically young mid-ocean ridges. The rock and pore fluids in such regions are likely to be hot at shallow depths; additional engineering development to allow drilling and measurement at high temperatures is now underway.

Roughnecks prepare the drill string aboard *Glomar Challenger*.

James Broda

The Ocean Drilling Program, presently funded by the National Science Foundation over the next five years with an option for extension, is managed by a consortium of 10 major oceanographic institutions including WHOI called Joint Oceanographic Institutions, Inc., or JOI. Scientific planning for ODP will be done by the Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES, of which WHOI is also a member), an international organization which also did the planning for DSDP. Texas A & M University will be the drilling vessel contractor. Official participation from many nations is expected, and a broad spectrum of marine scientists and geoscientists from throughout the world will soon be participating in new scientific discoveries about the origins and evolution of the earth and the oceans and their resources.

DSRV *ALVIN*/R/V *ATLANTIS II* Conversion

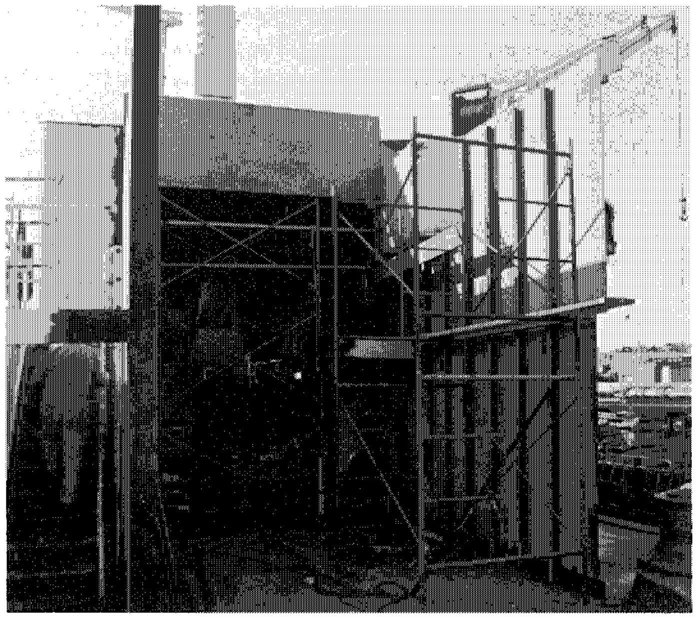
George D. Grice

Following more than two years of rehabilitation, repair, modification, and installation of new handling and scientific equipment to provide support for submersible and other operations, Research Vessel *Atlantis* II and the Deep Submergence Research Vessel *Alvin* were scheduled to depart Woods Hole in January 1984 to begin an 18-month voyage to the Pacific. *Atlantis II*, commissioned in 1961, has completed 111 cruises and logged over 741,177 miles. *Alvin*, constructed in 1964, was operated from Research Vessel *Lulu* until August 1983 and had completed 1,328 dives in the Atlantic and Pacific Oceans prior to January 1984.

Although a very successful operation, there were recognized limitations to *Lulu* as a tender for *Alvin*. The major drawbacks were its inadequate laboratory space, insufficient berths, limited endurance, and slow speed. Many *Alvin* programs required an additional large support ship to provide accommodations and the necessary laboratory space. Consideration of these limitations and the high cost associated with operating two support vessels were compelling issues in selecting *Atlantis II* as a submersible support ship. With funding provided by the National Science Foundation, the Office of Naval Research, and the National Oceanic and Atmospheric Administration, *Atlantis II* and *Alvin* were refitted and are prepared to support the increasing demands of the new scientific programs.

Concurrent with the modifications required to support the submersible operations, significant improvements and upgrading of *Atlantis II* were made during the planned mid-life rehabilitation program that was initiated in 1981. This program was extensive. It included the repair, upgrade, or replacement of certain structural components, air conditioning and ventilation systems, steering mechanism, exterior door and topside windows, sanitary systems, hull and decks, staterooms, passageways, mess facilities, galley, library, and safety systems. The lifeboat was relocated to provide clear deck space for accommodating vans and portable equipment. Improvements were also made to significantly increase the scientific capabilities of the ship. Chief among these was the upgrading of the clutches to permit prolonged operation at slow speeds. The main laboratory, computer (lower lab), hydro, and top laboratories were completely refurbished, and a new salt water system installed.

Several new pieces of equipment were added, each of which provides significant improvement to previous capabilities. A 750 h.p. trainable bow thruster has replaced the original undersized 250 h.p. bow thruster. The new bow thruster greatly improves the ship's maneuverability, and in conjunction with the new clutches, will permit precise control of the ship during the deployment and recovery of scientific equipment including *Alvin*. A new marine crane rigged to handle the trawl wire and



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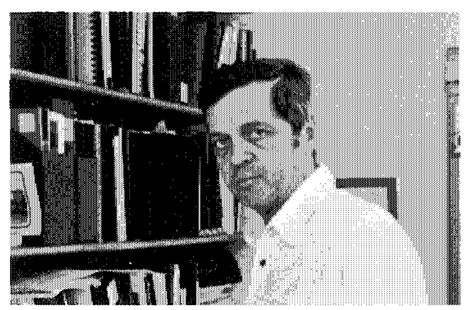

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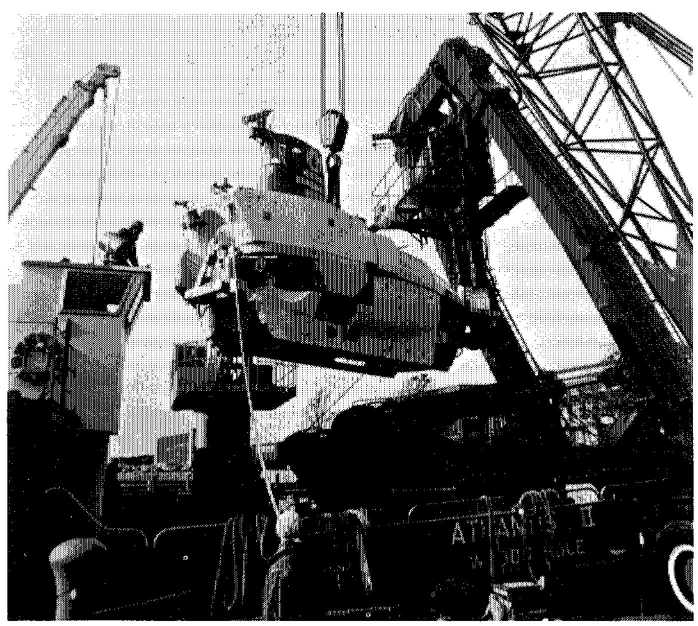
Top: The deck hangar for *Alvin* takes shape in January 1983. Middle: George Grice. Bottom: Transfer of *Alvin* to *Atlantis II* 18 November; the control shed for the lift system is at left.



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provided with a longer boom and heavier lifting capability than the previous one has been installed. The hydrographic winch was overhauled, and a modified fairlead and A-frame provided.

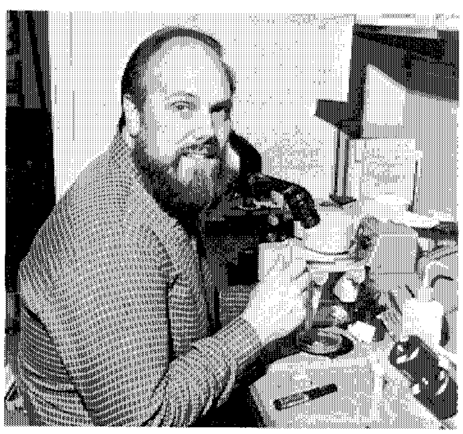
While in drydock in the summer of 1983 a transducer array was installed on the hull of *Atlantis II* as part of a new seafloor mapping system called Sea Beam. When Sea Beam's electronic package is aboard the ship and connected to the array, an underway contour map of the sea floor equivalent to an area of seventy-five to eighty percent of the water depth below the hull is produced in virtually real time. With such instantaneously available information, scientists will have the ability to examine bottom topography while at sea rather than after its reconstruction in the laboratory some months later. Bottom topographic maps will, of course, be of immense value to those planning *Alvin* dives in previously unexplored sites.

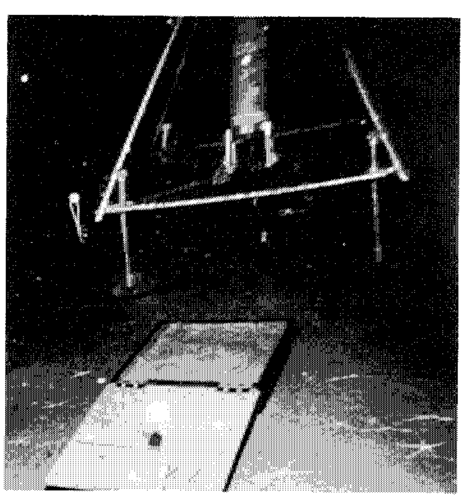
To operate *Alvin* from *Atlantis II* required the development of a lift system, installation of a shelter hangar, and associated maintenance shops. The lift system is a stern mounted hydraulically operated A-frame with overhead winch and telescope leg that attaches to *Alvin*. The A-frame is 41 feet in height and is capable of lifting thirty tons (*Alvin* weighs approximately 17 tons). Once attached, *Alvin* is hoisted from the water and placed on deck rails for transport into the hangar, aft of the main laboratory on the fantail and 28-feet long and 13-feet wide. Three *Alvin* support shops are located on the port side adjacent to the hangar.

Several modifications were made to *Alvin* for the new lift system, including strengthening the internal titanium frame to facilitate lifting the submersible at a single point near its center of gravity. A second smaller line attached to the sub's stern provides additional stability during launch and recovery. The only notable exterior change has been the shape of the sail.

This conversion has been a major task for our Marine Department, Mechanical, Electrical and Carpenter shops, ship's crew, and *Alvin* Group for more than two years. Their efforts have produced a greatly improved ship – one that not only can support submersible operations when *Alvin* is aboard but can also provide support for oceanographic programs requiring sophisticated facilities, instrumentation, and equipment. *Atlantis II* is the most versatile ship in the U. S. research fleet.

Frank Medeiros





Top: Fred Grassle. Bottom: Free vehicle used to transport recolonization trays to the bottom for placement by *Alvin*.

DSRV *Alvin* Bottom Station Studies

J. Frederick Grassle

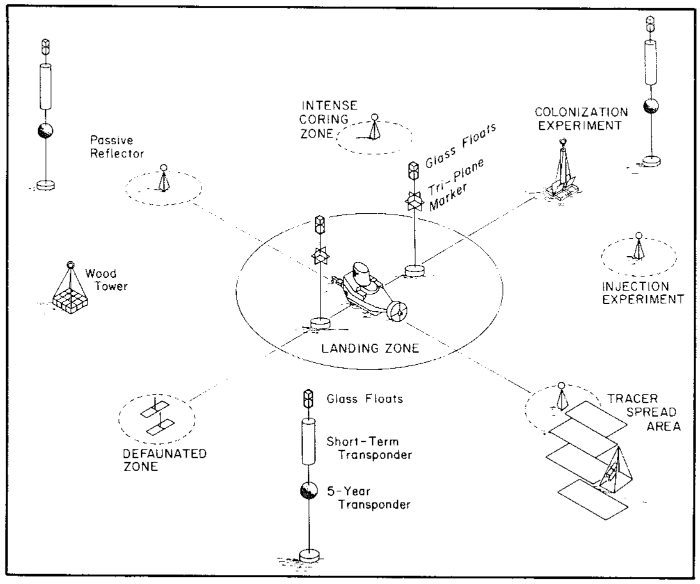
The deep-diving submersible *Alvin* has been the primary means for conducting experiments at the deep-sea benthic boundary layer. Such experiments are possible with free vehicles, but they tend to be more cumbersome with less certainty of successful recovery after long periods on the bottom. In 1982, Dr. Robert Whitlatch of the University of Connecticut and I used *Alvin* to complete part of a series of experiments in the Panama Basin at 4,000 meters (13,120 feet) depth.

We spread a size range of fine glass beads on the sediment surface in 18 separate plots and returned to the sites at intervals of 3, 5, 7 and 400 days. These experiments with spread particles were designed to determine how sediment turnover by animals (bioturbation) can alter sediment stability, vertical profiles of sedimentary materials, sediment diagenesis, and the movement of particulate materials across the sediment-water interface. In each plot particles were evenly distributed from a honeycomb frame on legs with a plastic slide for *Alvin*'s mechanical arm to pull. This simple direct approach using *Alvin*'s manipulative capability was adopted following problems with a more complicated device. By taking many adjacent sediment samples we can isolate individuals and separate the various ways animals process sediment in the deep sea. The animal activities resulted in transfer of the larger particles to deeper sediment layers.

Increased knowledge of the feeding habits of individual species will help explain the coexistence of so many species on each small patch of sea floor.

Other examples of the potential for long-term in situ experimentation could be made from revisits to a deep ocean station at 3,600 meters (11,800 feet) depth south of New England over a period of eight years. On an expedition to hydrothermal vents at the Galapagos Rift in 1979, individual mussels were notched in February and retrieved after ten months from a depth of 2,500 meters (8,200 feet). Studies of rates of colonization over periods of years at such sites enable us to determine rates of growth and survival of deep-sea populations.

Future studies at bottom stations will involve even more closely coordinated sampling of the chemistry of sediments and organisms. In the Guaymas Basin, Gulf of California, hydrothermal fluid circulates through a thick layer of pelagic sediments. These hydrothermal vents in soft sediments are characterized by patches of hydrogen sulfide and bacterial mats in some places and petroliferous sediments in others. Sharp vertical and horizontal changes in flux of hydrothermal fluid and sediment chemistry make this site at 2,000 meters (6,250 feet) depth an ideal laboratory for studying the interrelationships of bottom animals, microorganisms, and organic and inorganic chemical processes. Submersibles such as *Alvin* are presently the only means available for obtaining replicate samples in this environment.



A plan for a permanent bottom station. Various experiments involving either tracers or perturbations of benthic communities are shown at positions that can be relocated in the navigation net consisting of three long-term and three short-term transponders.

Vicky Cullen

The Use of DSRV *Alvin* for Microbiological Studies

Holger W. Jannasch

Major functions of microorganisms in the ocean as the "world's largest sink" are the decomposition of organic matter, breakdown of pollutants, and regeneration of nutrients. For qualitative and quantitative assessments of these activities in deep water and sediments, we study the effects of in situ conditions, mainly temperature and pressure, on bacterial growth and metabolism. The most important part of this work consists of in situ incubation studies with the aid of *Alvin*. For this purpose we developed, with the help of engineers Clifford Winget and Kenneth Doherty, a variety of devices for *Alvin*-operated inoculation and deposition of certain solid and dissolved substrates on the ocean floor at permanent stations at 1,800, 3,600, and 4,000 meters (5,900, 11,860 and 13,120 feet) depth in the North and Central Atlantic. Precharged with radiolabeled tracers, water and sediment samples are left on the ocean floor for incubation periods of days, weeks, or months. After relocation of the sta-

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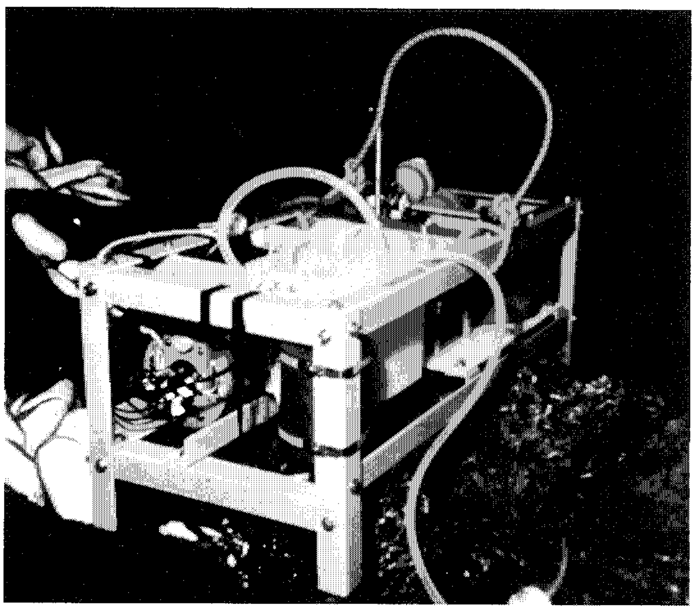
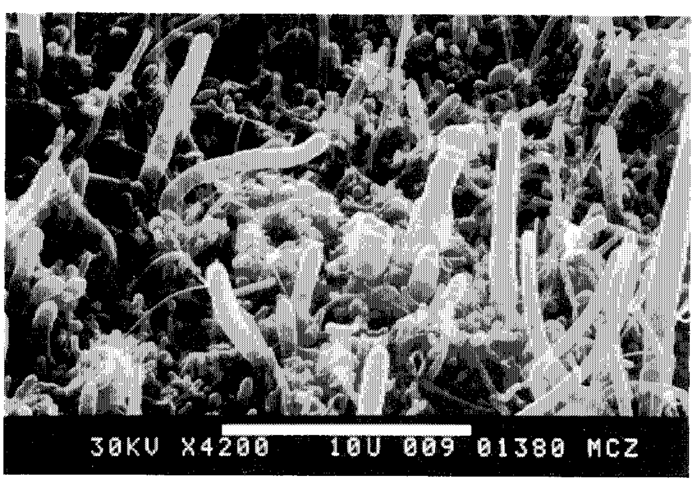
tions, the samples are picked up by *Alvin* for analyses in the laboratory. The *Alvin*-related technology used in these studies initiated the development of pressure-retaining bacteriological water samplers and ultimately the construction of a device permitting the pure culture isolation of deep-sea bacteria in the absence of decompression, an instrument designed by Kenneth Doherty and built by Martin Woodward. This work has resulted



David Karl, University of Hawaii



Carl Wirsen/E. Seling

Top: A pumping system placed at the edge of a warm vent pocket (23°C) at 21°N. In an automated succession the vent water is pumped from an extended intake nozzle (foreground) into an 8-liter bag and then through various filter arrays. Bottom: Scanning electron micrograph, magnification 4,200x, shows microorganisms which grew on artificial surfaces placed into a vent plume for ten months.

in data quantifying the slow-down of specific microbial activities in the deep sea as well as in studies on certain deep-sea bacteria specifically adapted to life at high hydrostatic pressure and low temperature.

Our notion of the deep sea as a universally nutrient deficient and cold habitat had to be qualified when thriving populations of certain animals were discovered clustered around hydrothermal vents in depths of 2,500 to 2,600 meters (8,250 to 8,575 feet). It was found that various types of microorganisms, mainly sulfur bacteria, used reduced inorganic compounds of the hydrothermal fluid as sources of energy for the chemosynthetic production of organic matter. Thus, in these light-independent ecosystems, bacteria are replacing the photosynthetic plants as the base of the food chain. Nowhere was the use of *Alvin* so important and indispensible as for studying these hydrothermal deep-sea vents. Very accurate sampling and placing of instruments were required for work at specific locations in the space scale of a few inches. At the same time, the larger carrying capacity of *Alvin* was required to lower heavier instruments in exact positions near vent openings. A new complex pumping system (figure top left) was designed by Kenneth Doherty to be used for bacteriological and chemical samples of hydrothermal fluid undiluted by ambient seawater. While the instrument package (250 pounds) was one of the heaviest ever handled by *Alvin*, the nozzle at the end of a plastic intake tube required placement with the accuracy of one inch. At-the-spot decisions from in situ observations on the actual placement are essential for a most satisfactory scientific sampling program. The pumping system contains a variety of filter units as well as a large (8 liter) vessel for sampling unfiltered hydrothermal fluid.

There were a variety of other sampling and in situ-incubation devices used by *Alvin* for microbiological studies at the vents. Anaerobic hydrothermal fluid from warm vents was collected with a "syringe poker" inserted into vent openings and triggered by contact. Six parallel samples taken by *Alvin*-operated syringes and left at the vent for several periods of incubation were used for measuring the in situ rate of chemosynthesis. A sampling device was also inserted into 350°C (660°F) 'black smoker' hot vents for the collection of freshly formed mineral deposits on a fiberglass matrix. Furthermore, perforated boxes containing a large variety of surface materials for attachment and growth of microbial cells were placed into and near vent openings for recovery at prolonged incubation times. A large number of different morphological and physiological types of bacteria were later observed on those materials by electron microscopy (figure bottom left). On our latest cruise to the 21°N vent site, *Alvin* operated a 220-pound pressure-retaining water sampler for the first time in these vent studies. The 1-liter sample was incubated aboard the escort vessel with an added radiolabeled tracer and at warm vent temperature (23°). The data of this experiment and its proper controls concern the degree of pressure and temperature adaptation of the chemosynthetic vent bacteria.

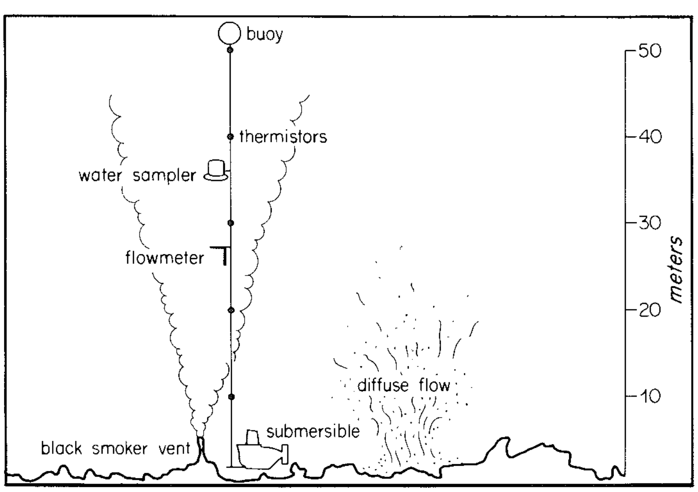
Use of DSRV *Alvin* as a Deep-Sea Platform for Observation, Sampling, and Instrumentation

Michael J. Mottl

The use of submersibles for scientific work in the deep ocean has grown enormously in the past decade. Prior to that period our knowledge of seafloor processes was too primitive to have benefited much from the detailed and small-scale studies which are the forte of manned submersibles such as WHOI's *Alvin*. Large scale studies were required which could be done faster and at less expense using surface ships. The deep seafloor could be adequately observed, measured, and sampled via instruments and equipment lowered and towed on cables.

We may yet return to this situation, given the increasing capability and sophistication of towed vehicles. In the meantime, the manned submersible is in its heyday. It is the only tool presently available which allows us to observe and sample on a fine scale those localized seafloor processes and products which are now known to be critical to understanding the larger scale processes studied from surface ships.

The prime example on the deep seafloor is the process of crustal formation along the axis of the mid-ocean ridge system. Volcanism and hydrothermal activity accompanying crustal formation are highly localized phenomena. While direct observation of the deep seafloor is difficult enough by itself, coupling observation with detailed sampling and precise navigation is even more difficult. Using *Alvin* and France's *Cyana*, we have observed submarine hot springs and sampled their 350°C (660°F) effluent from orifices only a few centimeters across. We have sampled organisms from the diverse vent community and mapped their distribution on a scale of meters. We have sampled ore-grade sulfide deposits from specific sites and directly documented their geologic context. We have sampled rocks from individually mapped lava flows, and hydrothermal minerals from individually exposed veins. All of these feats have been accomplished best, and at present could only have been accomplished, by using manned submersibles.



Besides observation and sampling, however, a new use for submersibles has been found in the past few years: that of instrument platform. *Alvin* was first used extensively as a platform for geophysical measurements during the RISE (Rivera Submersible Experiments) program in 1979 on the East Pacific Rise axis near 12°N. Detailed measurements were made of rock magnetization, propagation of sound and low-frequency electromagnetic radiation through the sea floor, and the gravity field, the latter 10 to 100 times more accurate than measurements made at the sea surface.

In 1984 Dr. Richard Von Herzen and I will be using *Alvin* as an instrument platform in another novel configuration. We are studying the chemical and physical processes which occur in the hydrothermal plumes which form above hot spring fields along the mid-ocean ridge, when the warm spring water rises and mixes with ocean bottom water. Chemical processes in these plumes account for the fate of much of the heavy metal input delivered by the hot spring vents, while the physical nature of the plumes should yield a measure of the total heat output from the vent field as a whole. Our plan is to use *Alvin* as a stable platform for an array of measuring and sampling instruments which will be suspended above the submersible on a buoyant mooring line, as shown in the illustration at right. By navigating the submarine through a tight grid pattern we will determine the three-dimensional thermal structure of the plume associated with a vent field. At stations within the grid we will stop and measure the flow velocity in three components and take water samples and additional measurements.

Only a submersible could accomplish this task. It can be navigated and maneuvered precisely, it can remain stationary while the flow velocity is measured, and it permits visual observations and temperature measurements in real time which are required to delimit the boundaries of the survey. This capability and versatility, coupled with the competent, flexible and highly professional assistance provided by *Alvin*'s support group of pilots and engineers, are what assure the research submersible a strong future on the frontiers of marine science.

Left: Use of *Alvin* as a maneuverable instrument platform for studying hydrothermal plumes. Right: Mike Mottl.

Shelley Lauzon

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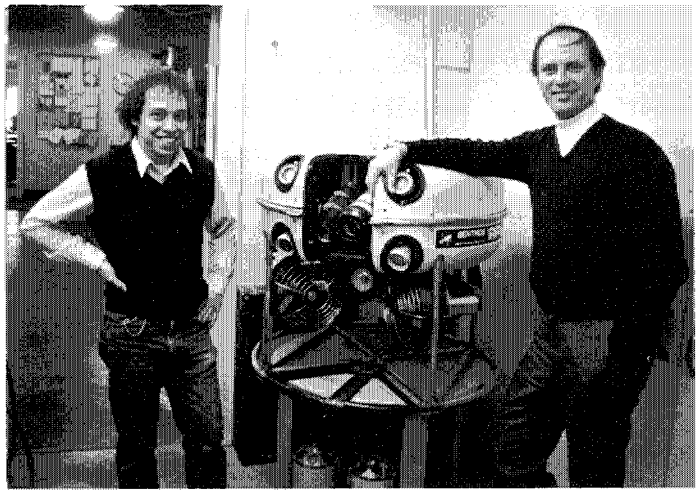
The Deep Submergence Laboratory

Robert D. Ballard, Dana R. Yoerger and
William K. Stewart

In recent years major discoveries have been made in the oceans and on the sea floor, exciting efforts which have only begun to illustrate the potential importance deep-sea exploration may play in man's long-term utilization of the planet. Important technological advances being made in such areas as video imagery and enhancement, robotics, fiber optics, and microprocessing hold promise for the development of new exploration vehicles. Our challenge is to take the lead in applying these new developments to marine related problems. The Deep Submergence Laboratory (DSL) in the Ocean Engineering Department is dedicated to the development of advanced undersea exploration vehicles and their ability to function on a wide variety of research vessels in a cost-effective manner. The suite of instruments now operated by DSL includes the color camera systems ANGUS and Mini-ANGUS, the navigation system ACNAV, side-scan sonar like Sea Marc I and Klein's Hydroscan for deep and shallow water high resolution acoustic imaging, and several remotely piloted vehicle systems.

The ANGUS (Acoustically Navigated Geological Underwater Survey) system, the first search and survey system operated by DSL, was designed to work primarily in extremely rugged volcanic terrain to depths of 6,000 meters (20,000 feet). As a result, its various subsystems are mounted within a heavy-duty steel frame capable of withstanding a jarring head-on collision with vertical outcrops of rock. Unlike other survey systems, ANGUS maintains continuous visual contact with the bottom, flying at an altitude averaging 10-15 meters (30-50 feet above the bottom). Up to three large capacity 35 mm color cameras each having 3,200 frames, normally taken at 20-second intervals, together photograph a swath of sea floor 60 meters (nearly 200 feet) in width. Batteries power electronic strobe lights, permitting the sled to be flown at higher altitudes and to "see" further than conventional deep-sea camera systems. The temperature of the water the system is passing through and the height of the sled above the bottom are telemetered back to the ship; cable can be hauled in or let out to maintain the desired altitude. This highly portable system, used on a standard ½-inch trawl wire found on most oceanographic ships, includes in one container a complete color processing facility modified to operate on warm seawater. Film can be processed and analyzed within four hours.

A small-scale version of ANGUS, known as Mini-ANGUS, resulted from a 1981 cruise during which a broken trawl winch on the ship prevented the use of ANGUS. In order to continue the planned work, a small-scale version was built aboard ship which could be operated using the ship's ¼-inch hydrographic wire and winch. Since hydrographic winches are found on many small ships without trawl winches, Mini-ANGUS has since been operated as the primary survey camera on a number of cruises. It has a capacity of 800 to 1,600 frames (compared to



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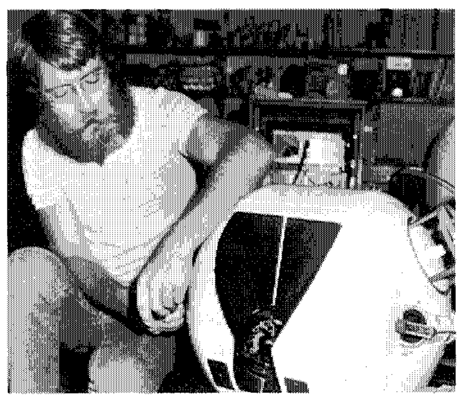

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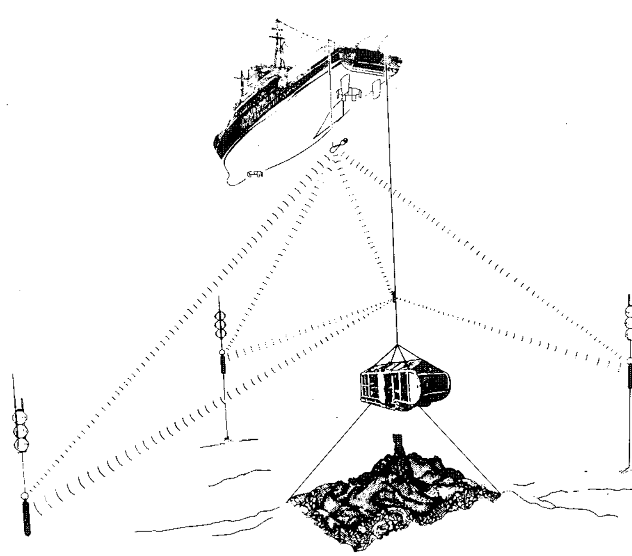


Above: Dana Yoerger (left) and Bob Ballard with the RPV-430. Middle: Ken Stewart and AMUVS. Bottom: Schematic of the ANGUS system, operated from R/V *Knorr*.

ANGUS' 7,000 to 21,000 frames) and can be operated by one person, reducing its overall costs. Mini-ANGUS can utilize one or two color cameras and be outfitted with a temperature telemetry system and down-looking sonar like ANGUS. Because its lights are less powerful than those on ANGUS, the area photographed is much smaller and the vehicle is flown at a lower altitude of 5-7 meters (16-22 feet).

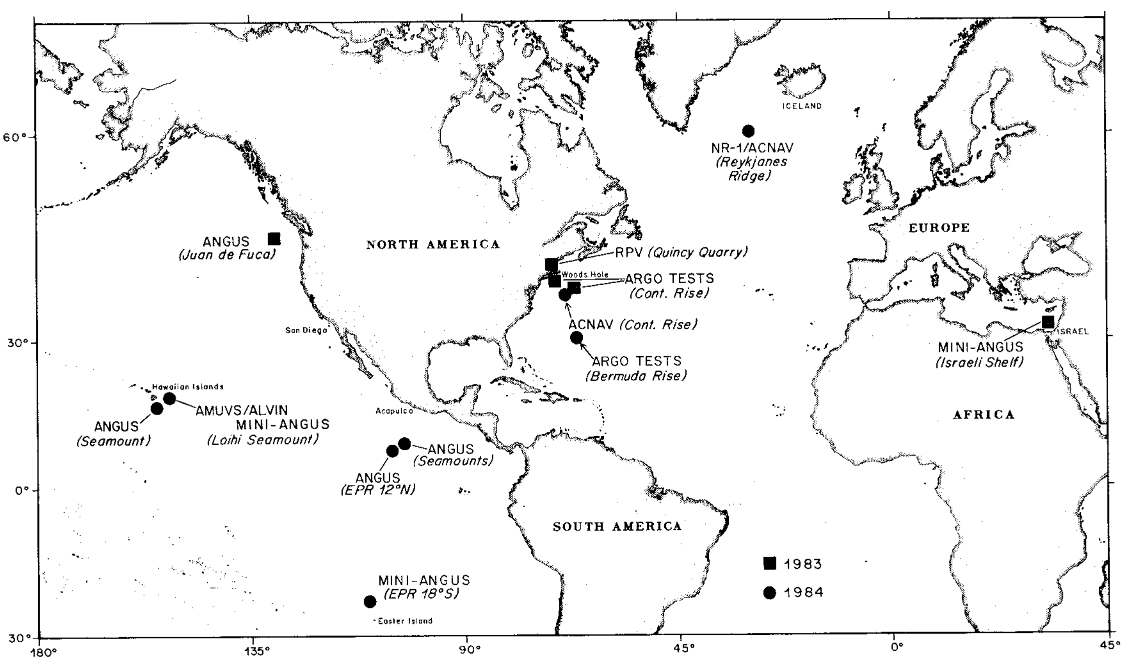
A by-product of the *Alvin* submersible program has been the development of the ALNAV (Alvin navigation) system to accurately track the submersible's course over the bottom. This system was modified to track any system placed over the side, whether it was a submersible, towed camera, or surface drifting sonobuoy. ACNAV, or acoustic navigation, was the result. Plots generated by a variety of software packages make it easy for the users to place photographic interpretations along the track and create numerous map products. Although ACNAV has been used primarily to track ANGUS and Mini-ANGUS, it has also been used to install a variety of instrument packages on the ocean floor (camera tripods, seismographs, etc.), to navigate dredge hauls, for use in piston coring and heat flow measurements, and to maneuver CTD or water samplers into a desired sampling position over deep-sea hydrothermal vents.

DSL also currently operates two remotely piloted or operated vehicles (ROVs) which provide unique capabilities and support various basic and applied research efforts in ROV control systems, man-machine interface design, and manipulator systems. AMUVS (Advanced Maneuverable Underwater Viewing System) is a small ROV capable of operating to a depth of 6,000 meters. Originally designed to operate from the Navy bathyscaph *Trieste II,* it was transferred to DSL in 1982 to interface with *Alvin* for a variety of future Navy programs. In the midst of a major refurbishment, AMUVS is primarily a highly maneuverable viewing platform, although plans call for placement of a simple manipulator on the vehicle. Following the refurbishment program, AMUVS will be tested on *Alvin* off the island of Hawaii in late 1984 or early 1985.

Another vehicle, the RPV-430, serves as a platform for basic and applied research in supervisory control, man-machine interface design, and robotics and to assist in the design of a 6,000-meter system called Jason (described later). A specially-designed manipulator will provide the vehicle with dexterous manipulation capabilities and the ability to carry moderate loads.

Recent field programs have included use of Mini-ANGUS off the Israeli coast to document the sea floor along the route of a proposed pipeline for a new waste disposal facility near Tel Aviv, and the use of ANGUS off the northwestern U.S. coast as part of a long-term investigation of the Juan de Fuca and Gorda Ridges in hopes of locating massive polymetallic sulfide deposits within the U.S. Exclusive Economic Zone. Since the primary goal of DSL is to accelerate man's exploration of the deep sea floor, an important aspect of the Laboratory's activities is the actual use of its survey and mapping systems in major oceanographic expeditions. Our major focus in this area is the Mid-Ocean Ridge system, a 40,000-mile undersea mountain range which covers 23 percent of the planet's total surface area. DSL staff have participated in expeditions to the Mid-Atlantic Ridge, Cayman Trough, Galapagos Rift and East Pacific Rise, where long-term investigations are underway on seafloor spreading. In 1984 cruises for geological studies are planned with the French and their submersible *Cyana* on the East Pacific Rise near

DSL field programs conducted in 1983 and proposed for 1984.



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Easter Island, with *Alvin* for exploration of a series of seamounts off the coast of Mexico and Central America, and to the Reykjanes Ridge south of Iceland using the nuclear research submarine NR-1. *Alvin* will be used in early 1985 for dives to the Loihi Seamount south of the island of Hawaii. During this voyage AMUVS will be tested and Mini-ANGUS used in mapping and sampling work.

The methodology of deep-sea exploration can be divided into four major phases, each with its own technology: topographic surveying, large area reconnaissance and mapping, detailed observation and precision sampling, and the measurement of time dependent phenomena. In topographic surveying, Sea Beam is becoming the international standard. DSL, therefore, is developing imaging software to make it easier for the user of Laboratory technology to see and understand the larger topographic framework in which he is working. In large area reconnaissance, DSL believes the Argo imaging system under development will make a major contribution. In the area of detailed observation and precision sampling, the Laboratory has played an important role in the development of *Alvin* and its associated mapping and sampling technology; emphasis has been shifted recently, however, to development of unmanned remotely operated vehicles like the Jason system. In the measurement of time dependent phenomena, DSL has concentrated in assisting scientists interested in establishing long-term bottom stations and expects to place a stronger emphasis upon such work once the dual vehicle Argo/Jason system becomes operational.

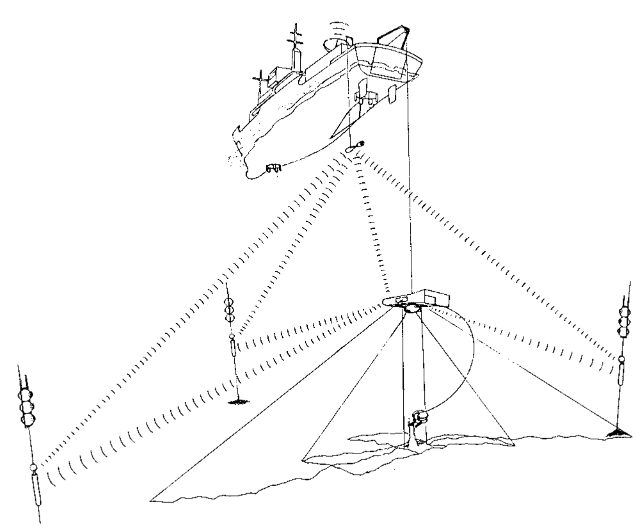
Argo is a deep-towed vehicle capable of operating in 6,000 meters (20,000 feet) of water suspended from a surface ship by a winch-driven, steel-armored coaxial cable able to support more than 35,000 pounds and transmit a variety of frequency signals. Equipped with a complement of superior sensors for deep ocean survey and inspection, Argo will be able to sustain dives measured in terms of days or weeks and dramatically increase our "bottom staying power" from present manned submersible operation levels. Argo will employ both acoustic and optical imaging systems; real-time video will be transmitted up the cable from a bank of cameras suspended below Argo in an imaging pod. These cameras provide the surface operators and scientists forward, side and down-looking views of the ocean floor. High energy strobes mounted on the main vehicle will flash every few seconds to provide lighting. Integration of this system with side scan sonar will provide wide area mapping capabilities with varying degrees of high resolution TV coverage – instant video pictures!

Surface operators will be able to interact with each sensor subsystem, and all subsurface data will be acquired on the surface for real-time processing and viewing as well as recording for post-mission processing and archival. Three operators will be responsible for the operation of Argo, the winch system and ship guidance. Video information from each camera displayed on operator consoles will aid in winch control; navigation and sonar data both will provide information for ship guidance. On board video editing capabilities will allow production of hourly, daily or mission summary tapes in an effort to reduce the amount of TV data into manageable proportions. In addition, still frame storage in the form of video discs will be available for random access of reference frames and mosaic production.

Users of the Argo system will be able to sit in the surface control center and view an underwater landscape as large as four acres, with immediate access to a wide variety of other information. Argo will provide a garage for Jason, a tethered self-propelled vehicle with three-dimensional mobility. Surface operators who find areas of interest on the ocean floor via Argo's imaging system can deploy Jason for a closer, detailed look. Samples can be collected with Jason's mechanical arms, and its stereo color TV "eye" will transmit high-quality pictures to the surface ship. Long-range plans call for images from the Argo/Jason system to be relayed via satellite throughout the world.

Development of this sophisticated and complex imaging system will take time. Initial emphasis is being placed on the construction of Argo, with sea tests planned for the summer of 1984. Jason will be operational by the summer of 1986.

DSL's ultimate goal is to replace the need for expensive and limited use of manned submersibles through the application of teleoperator (manipulator) technology in remotely operated vehicles. Research is underway at DSL in many aspects of this exciting field.



Stefan Masse

Schematic of the Argo/ Jason system operated from R/V *Knorr*.

The Sea Beam System

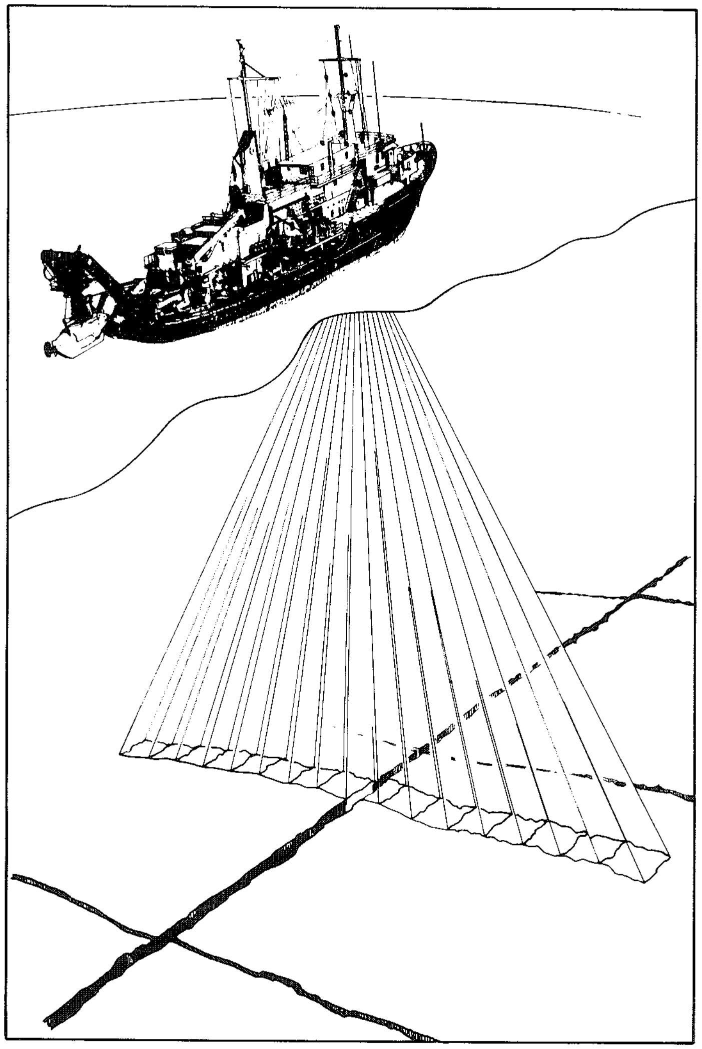
Brian E. Tucholke and Ann Martin

The morphology of the sea floor is a concern central to almost all oceanographic disciplines. Generations of oceanographers since the 1930s have observed the sea floor as a two-dimensional cross section created by returns of successive pings of sound from the bottom. Now a new system, Sea Beam, sends and receives a fan of sound to produce real-time strip contour charts of the sea floor beneath and to both sides of a ship's hull.

A Sea Beam transducer array for multi-narrow-beam echo sounding was mounted on the hull of the Institution's R/V *Atlantis II* in late 1983; the Sea Beam system, including an echo processor system in one of the ship's laboratories, will be tested in 1984. Sea Beam embodies the greatest advance in echo sounding technology since World War II for the routine acquisition of accurate bathymetric data. The system was developed for the U.S. Navy over a period of 20 years, and it commercially available from the General Instrument Corporation.

A joint proposal by members of NECOR (Northeast Consortium for Oceanographic Research), comprised of Woods Hole Oceanographic Institution (WHOI), Lamont-Doherty Geological Observatory (LDGO), and the University of Rhode Island (URI), was funded by the National Science Foundation and the Office of Naval Research to allow acquisition and installation of a bathymetric mapping system suitable for use by the three institutions. The principal investigators are Brian E. Tucholke (WHOI), Alexander Shor (LDGO), and Paul J. Fox (URI). The sharing of responsibilities and facilities by the three institutions for the Sea Beam system has the desirable effects of avoiding duplication and of more economical operation of research vessels through pooled inventories, standardization of equipment and documentation, and the common use of support personnel.

The NECOR Sea Beam facility includes two hull-mounted transducer arrays, one on R/V *Atlantis II* and one on Lamont-Doherty's R/V *Conrad,* and one echo-processing electronics unit that can be transferred between the two ships. The



Stefan Masse

Shelley Lauzon

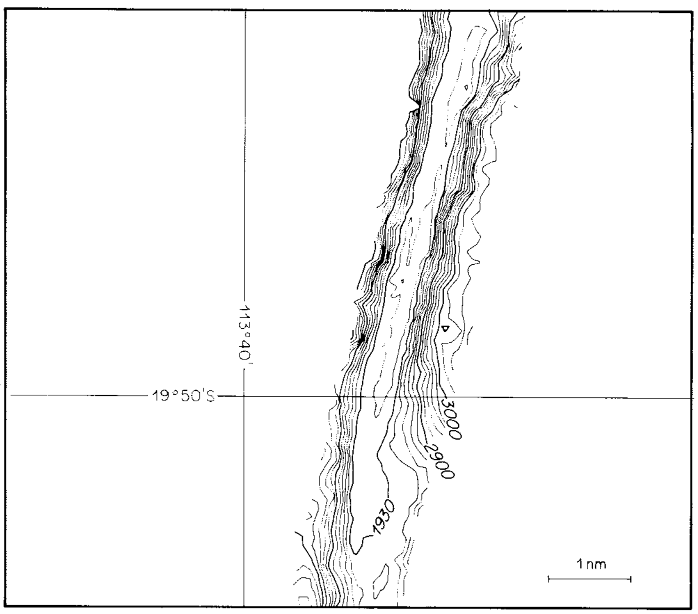
Above: Schematic of the Sea Beam system on *Atlantis II* showing the sixteen return echos off the bottom. Left: Ann Martin and Brian Tucholke.

Reports on Research

underhull arrays have been mounted on both ships, and the associated electronics presently are installed on R/V *Conrad.* The Graduate School of Oceanography at URI operates and maintains the electronics and designs the computer software for logging, processing, and archiving the data. NECOR expects to acquire a second set of echo-processing electronics within the next year with funding from the Office of Naval Research, providing both the *Atlantis II* and *Conrad* with full-time Sea Beam capabilities by 1985.

The Sea Beam system, consisting of a narrow beam echo sounder and an echo processor, can be used in water depths up to 11 kilometers (6.8 miles). A sonar beam is transmitted as a sound signal in each of 20 projectors along the ship's keel, forming a fan-shaped sound swath. Sixteen samples of the return echo – 8 port beams and 8 starboard beams – are received by a 40-hydrophone array mounted athwartship. The transmitted beam is stabilized to within ¼° of true vertical for ship's pitch and roll angles of ± 10°. A vertical gyroscope is used so that the returned signal is adjusted for the ship's vertical. Before display, the echo processor takes into account

Courtesy P.J. Fox, URI



Sea Beam swath from the eastern equatorial Pacific following the axis of the East Pacific Rise. The ship track ran along the center of the swath; numbers indicate depth in meters.

the ship's heading, pitch, roll, and depth. The contour interval and scale plotted are set by the operator.

Coupled with good navigation, the Sea Beam system can accurately map approximately 1,900 square kilometers/day (750 square miles) of sea floor in water depths of 5 kilometers (about 3 miles). The crosstrack profile is monitored on a video screen, and a real-time contour chart of the area beneath the ship, centered on the ship's path and representing a width about 80% of the water depth, is continuously plotted on a flatbed pen plotter. The strip chart is annotated according to vertical depth in meters, ship's heading, time, and contour interval (meters); tickmarks are drawn on alternate contour lines to show slope directions. Detailed surveys can be designed with overlapping swaths that are cross-correlated by the system's computer to provide a bathymetric map.

The bathymetric maps help provide answers to important questions dealing with volcanic, tectonic, and sedimentary processes that shape the sea floor. The system will provide the constraints needed to test and develop new models about tectonics, plate kinematics, sedimentation, mass wasting and abyssal circulation. These data are important to both basic and applied research in such diverse fields as geology, ocean engineering, physical oceanography, marine chemistry, and marine biology. In addition to its use as a mapping tool, Sea Beam allows an investigator to deploy near-bottom instruments precisely with respect to seafloor features. For example, water sampling devices and current meters can be moored in narrow channels and canyons, or seismometers can be emplaced accurately for detailed geophysical studies.

Although Sea Beam is new to the U.S. academic community, it has been operational elsewhere for some years. Three multibeam swath systems, precursors of Sea Beam, have been in use by the U.S. Navy since 1965. The first Sea Beam was developed for the Australian Government in 1973, and systems have been in use aboard the French research vessel *Jean Charcot* (CNEXO) since 1977 and on the NOAA ship *Surveyor* since 1980. Scripps Institution of Oceanography recently installed a Sea Beam system on the R/V *Thomas Washington.*

The NECOR ships R/V *Atlantis II* from Woods Hole and R/V *Conrad* from Lamont-Doherty, together with the onshore facilities of the Graduate School of Oceanography at URI, will provide oceanographic institutions on the U.S. East Coast with a sophisticated bathymetric mapping capability and new insights into the processes that shape the ocean floor.

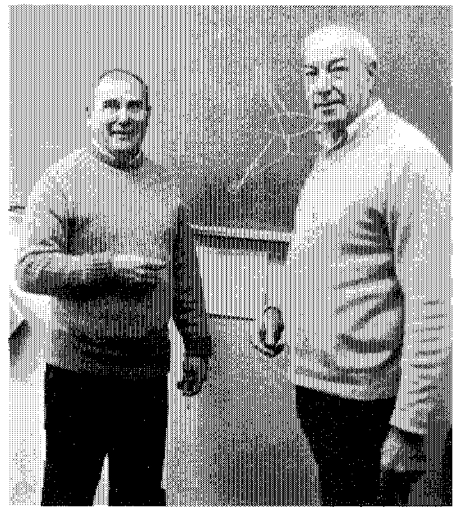
Mooring Technology

Robert G. Walden and Henri O. Berteaux

The Woods Hole Oceanographic Institution has developed a series of deep-sea moorings suitable for collecting oceanographic and meteorological data. Over the last decade moorings deployed at sea increased in numbers and sophistication; more than 800 have been deployed since the early 1960s. Moorings were designed, built and deployed for longer periods and in strong current regimes. Our standard intermediate moorings are now routinely deployed for one year; some of them successfully implanted in the Kuroshio current and in the Gulf Stream.

Fixed and free drifting platforms are measuring and transmitting data via satellite link meteorological and oceanographic parameters acquired at the ocean surface or at any depth in the water column. These platforms are spearheading the state-of-the-art in mooring technology; LOTUS (Long Term Upper Ocean Study) surface buoys (middle right) and RELAYS (Real Time Link and Acquisition Yare System) free drifters (bottom right) are examples of these advanced buoy systems. Certain scientific programs require instrumented platforms of an original and innovative type. Examples of these unique systems include the large IWEX (International Weather Experiment) trimoor and the moored JASIN (Joint Air-Sea Interaction) spar buoy (figure next page). More recently, the needs to rapidly deploy instrumented platforms and/or to access remote areas of the oceans prompted the use of long range aircraft which could deliver and parachute automatic self-deployed mooring systems like ADOM (Air Deployed Oceanographic Mooring).

The successful implantation and the high recovery rate of buoy systems set worldwide by WHOI are based on design, testing, quality control, and proven gear handling procedures. Mooring design (relying on both analysis and experience) is an important part of mooring components (buoys, mooring lines, anchors, etc.) which can satisfy, within reasonable cost and safety bounds, specified scientific and operational requirements such as instrument altitude, depth stability, and length of deployment. Mooring analysis, done these days with the help of comprehensive computer programs, determines the loads and deflections of cable structures as a function of environmental loading (wind, waves, and currents). The strength of mooring components is compared against the calculated loads. Predicted deflections are also compared against projected operational goals. The process is repeated until satisfactory results are obtained with adequate safety factors. Experience also plays an important role in selecting the type, shape, size, and material of deep-sea structure components. This experience is gained through systematic, controlled, documented testing and evaluation. Laboratory tests are routinely performed on synthetic and wire rope mooring line to determine actual breaking strength, elongation, torque, and creep characteristics. Connecting hardware is likewise proof tested.



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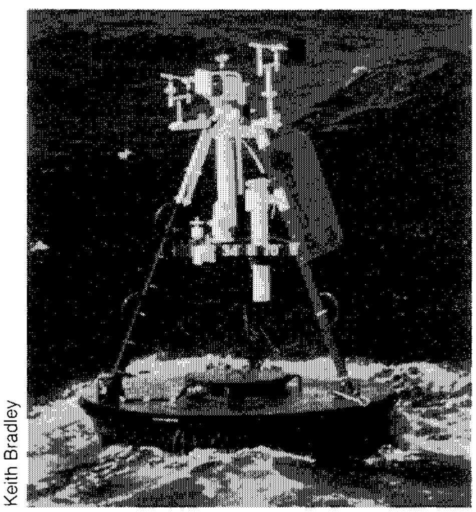

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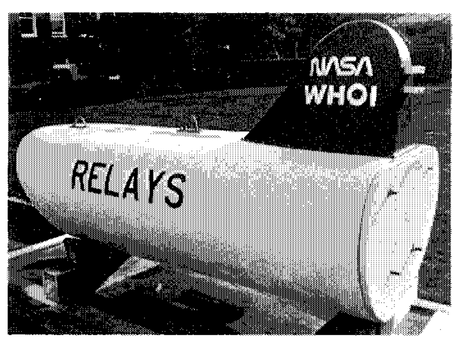

Shelley Lauzon

Top: Henri Berteaux (left) and Bob Walden. Middle: LOTUS surface buoy. Bottom: RELAYS free drifting buoy.

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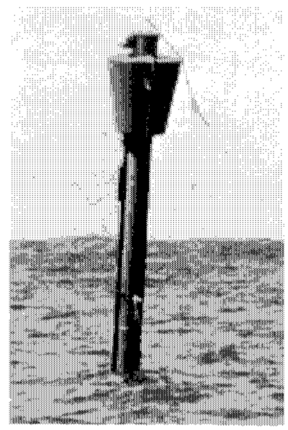
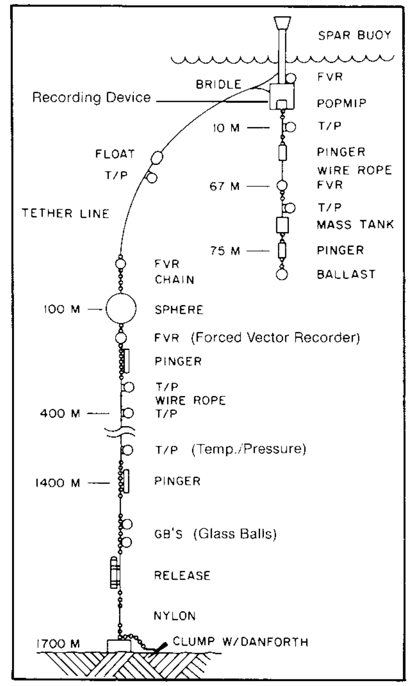
The ultimate measure of the effectiveness of mooring components is their ability to survive at sea. To this end special engineering moorings are set at sea specifically to expose mooring materials for great lengths of time. These moorings are recovered systematically and samples taken for laboratory inspection and testing. Corrosion, fouling, fishbite, and fatigue all contribute to the ultimate deterioration of mooring components. Corrosion is reduced through the use of heavy galvanizing on hardware and wire rope, insulation of dissimilar metals, and use of sacrificial anodes. Alloys such as Type 316 stainless steel and titanium are frequently used to inhibit corrosion. Fouling of instruments and buoy hulls can be largely controlled with anti-fouling paints. A tough plastic jacket on mooring lines reduces damage caused by fishbite.

Refined design techniques, new materials, and better handling methods now permit oceanographic measurements from moored stations throughout the water column for periods greater than one year. Special moorings have been developed which can be air-delivered. Multileg moorings have been deployed to permit measurements with both significant horizontal and vertical scales. Mooring life of three to five years now appears attainable.





JASIN spar buoy when deployed (above); diagram of the buoy (right).

The Long-Term Upper Ocean Study (LOTUS)

Melbourne G. Briscoe

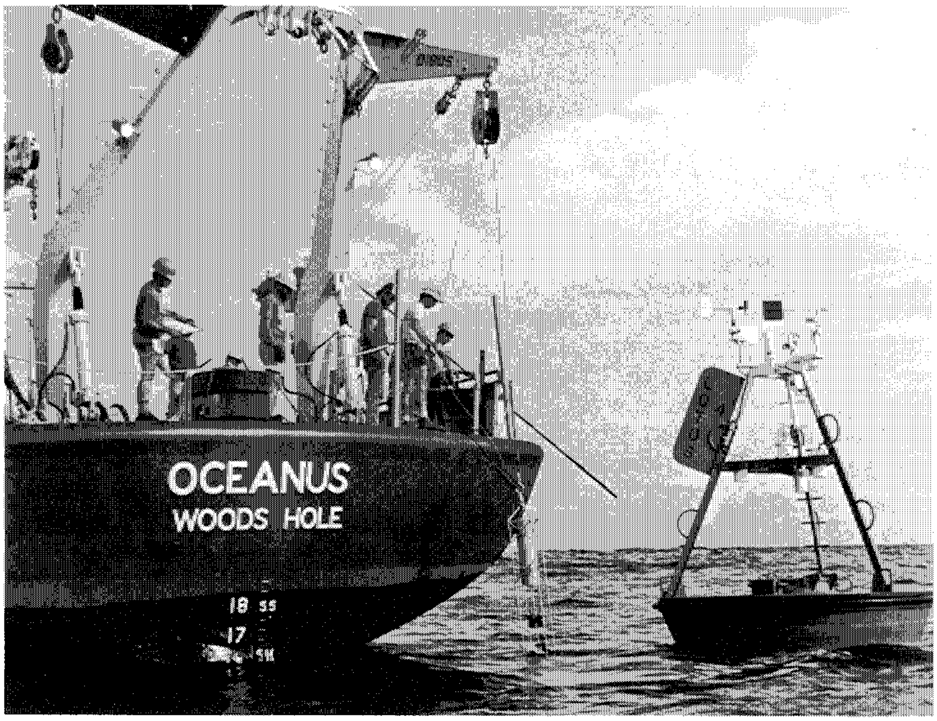
Most physical oceanographic experiments in the top few hundred meters of the open, deep ocean have been only a month or two long. Shops can rarely remain on station more than 3 or 4 weeks, and buoy systems and the instruments they carry have always had a reliability problem. Until recently, however, this limitation on the length of experiments has not been a major factor because many of the physical processes and scientific problems being studied in the upper ocean have not demanded long experiments.

It is the way of science and scientists, however, to seek the outer limits and greater context of whatever it is that is being studied, and physical processes in the upper ocean are no exception. No sooner do we discover that there are transfers of energy between the ocean and the atmosphere that take a few weeks to occur than we ask whether there are transfers that take several months or a season to happen.

From our work in the Joint Air-Sea Interaction project (JASIN) off the coast of Scotland in 1978, we learned that the energy in the internal wave field was not constant in time but varied about a factor of three larger and smaller over a few weeks. We tried to understand this in terms of other physical processes, such as variations in the local wind fields and surface waves; the conclusions were ambiguous partly because the experiment was only 6 weeks long and consequently only a few cycles of the various process rhythms were happening.

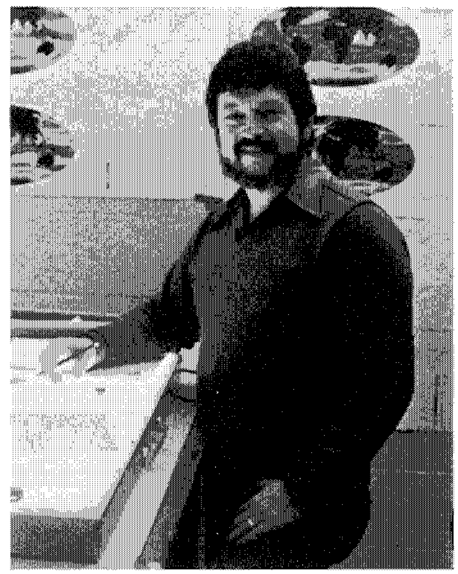
The internal waves were of interest because they are part of the chain of transfers of energy from large parts of the system of ocean circulation down to the small scales of mixing and dissipation. Internal waves in the ocean exist because of the combined effects of gravity and the rotation of the earth. The very large-scale motions like eddies and the Gulf Stream have mainly horizontal motions that are very much due to the rotation of the earth and Coriolis effects; very small-scale motions like turbulence have vertical components that have to work against gravity and can therefore dissipate energy. Internal waves span the gap and contain both horizontal and vertical motions and can pass energy from one to another. Current thinking is that the fluctuations in energy of internal waves over several weeks may reflect the transfer of energy from one part of the circulation system to another.

After JASIN we began to plan for an experiment that would be long enough to observe the rise and fall of internal wave energy and the changes in the larger and smaller-scale processes that might be sources and sinks of that energy. Since such a study would demand continuous observations over several seasons, in essentially the same geographical region, we selected moorings carrying a variety of instruments as the core of the program. What has happened in the three years since we started LOTUS (five years if you start counting from our first thoughts on the experiment) is a lesson in the practice of modern sea-



Mel Briscoe

Left: Deployment of a LOTUS mooring. The surface buoy at right has meteorological instruments on top. A near-surface current meter enters the water to its left. A 5,000-pound anchor secures the approximately three-mile mooring.

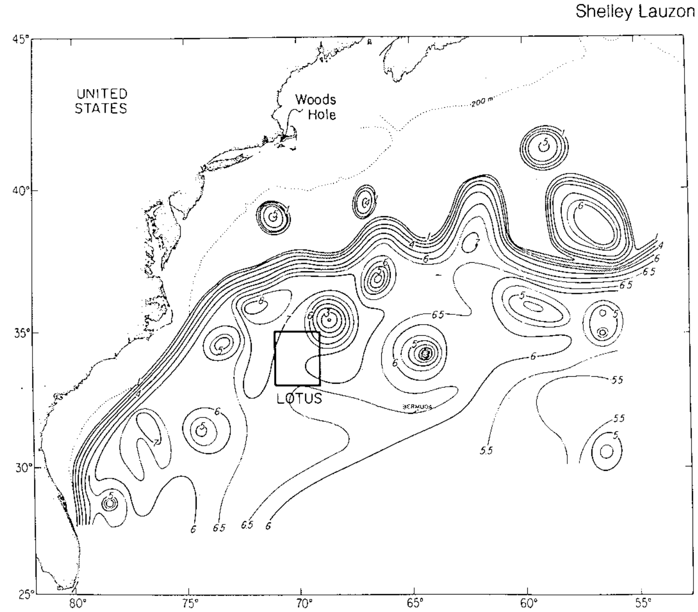


Shelley Lauzon

going physical oceanography. Many of the projects that we attempt are large, but they usually only happen once. LOTUS, because we are forced by our limited mooring endurance to acquire two years of data by performing four consecutive six-month experiments, has the feeling of going on and on. It is hard enough to get your equipment and people ready for one major field experiment, and it has proven even harder to get ready for four major field experiments.

We selected a site in the middle of the Sargasso Sea, about 500 miles south of Woods Hole and about halfway between Cape Hatteras and Bermuda (figure right). The bottom is flat there, the Gulf Stream does not directly influence the site, and it is about two days away by ship. Previous work at the site had established expectations about currents, temperatures, and winds, so it was possible to design our moorings and make a good guess about the engineering needs of the experiment.

In May 1980 we installed a surface mooring and a subsurface mooring at the site as engineering tests; we only wanted to gather a little performance information and assure ourselves that our moorings could survive the environmental conditions. When we returned in August to recover the surface mooring, it was gone. The surface float had disappeared and the rest of the mooring line had dropped to the bottom. We design our moorings with extra buoyancy at the bottom, just above the acoustic release, so that it is possible to recover the remains of a mooring in just such a situation.



Top right: Mel Briscoe.
Above: The LOTUS site.

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Unexpectedly, however, a combination of flooded instruments and lost buoyancy prevented the mooring from surfacing when we tried to recover it. Since we needed to get the mooring back in order to find out why we had lost the surface buoy, we dragged for the mooring remains with five miles of trawl wire and three large grapnels on cruises in November 1980 and May 1981, and were finally successful in August 1981.

Meanwhile, we had installed another test surface mooring using a newly designed buoy. Between the second test and discovering that a faulty piece of hardware costing $8 had caused the first test to fail, we convinced ourselves and the Office of Naval Research that we could successfully perform a two-year near-surface experiment in the open ocean by sequencing four 6-month surface moorings. LOTUS got underway in May 1982 with *Oceanus* cruise #119 to 34°N, 70°W, to set the mooring array.

By the end of 1983 we had completed the first 19 months of LOTUS, but not without incident. The first year went pretty well except that the second surface buoy (photo previous page) broke its mooring line in February 1983 and had to be recovered by the *Knorr* a few weeks later as she was passing by on her way home from Barbados. This was made possible by a satellite radio on the surface buoy that continuously transmits the buoy position and some engineering data back to Woods Hole. Not only could we tell that the mooring line had parted, we could determine that most of the scientific instruments were still hanging from the buoy, which made it worth the cost of having a ship divert its course to recover it. The entire satellite telemetry system, which used the ARGOS joint French-American network, started as an afterthought in LOTUS but has turned into one of the crucial elements that has allowed the experiment to proceed successfully.

Sometimes current meters themselves provide problems too. The photo at right shows the results of someone fishing near the mooring; probably the line broke and the fish went near the mooring to hide, and the trailing line tangled in the spinning propeller. Other instrument problems have been broken blades, failed bearings, and general electronic malfunctions. It is a tough environment.

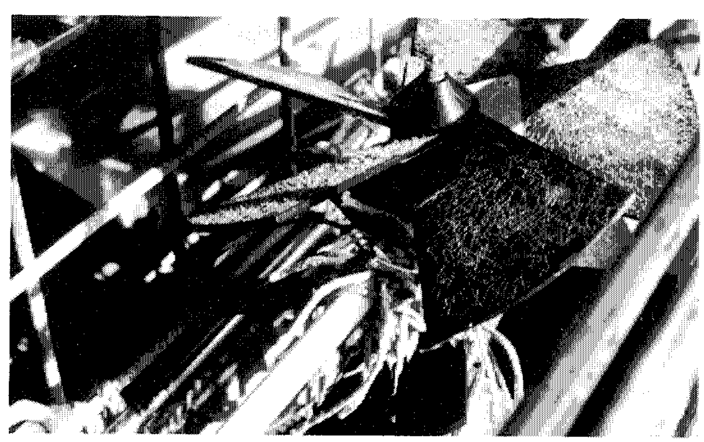
A second major problem occurred on the October 1983 *Oceanus* cruise to replace the surface buoy for the last 6-month segment of the experiment. A combination of poor weather and a faulty piece of handling equipment caused the replacement buoy to drop to the deck during launch and damage the buoy structure and some of the meteorological instruments on top. The buoy was brought back to Woods Hole to be repaired and was scheduled to be redeployed in January 1984. This will put a three-month data gap in the two-year experiment, in addition to the two-month gap already present earlier in 1983. Our concept of running a two-year experiment in order to obtain one year of good data is being dramatically justified.

Not all cruises go well. On the same *Oceanus* cruise where the buoy dropped, a brand new wave-measuring buoy that was in the water for the first time tangled with the ship's propeller and was lost. Hindsight indicates dozens of ways to have prevented both of these problems on that cruise, but none were apparent at the time. We learn from our mistakes, and we are continually learning. The LOTUS experiment has demanded new technology, a long attention span by scientists, engineers, technicians, and the Office of Naval Research. There have been a few problems, but the goal has been new knowledge about the ocean, and we have obtained that too.

From the first year of LOTUS we have been able to obtain the profile of eddy and internal wave energy from the surface to the bottom; no comparable eddy data exist anywhere, and the shape of the profile may cause some revision of ideas about how the atmosphere is able to force low-frequency motions in the ocean. At higher frequencies, we have shown the surprising result that internal wave energy at mid-depths is a minimum in the late summer and early fall, and reaches a maximum in the late winter. In fact, the internal wave energy looks suspiciously like the annual pattern of wind stress at the site, which has caused us to begin to look world-wide at the correspondence between internal wave energy and wind stress. It is possible that from this single experiment in the Sargasso Sea, even with all the technical difficulties, we may be obtaining new insights into the relationship of the atmosphere to the ocean at both low and high frequencies.

Experimental physical oceanography is not the typical scientific endeavor; it is very difficult to run a traditional "experiment" where one changes the parameters and learns from the response to the changes. We are more often in the role of observers and samplers, and have to take the situations as they occur. Our controls consist of how we design the observational program and its inherent capability to provide numbers on the expected phenomena, but still be sensitive to unexpected phenomena. It is possible to test hypotheses in the ocean, as in the laboratory, but the really good field experiments also provide new information and unexpected insights. LOTUS, time will tell, may be one of the good ones.

One of the hazards: fishing line tangled on a current meter on the LOTUS mooring.



Mel Briscoe

Oceanographic Observing Systems

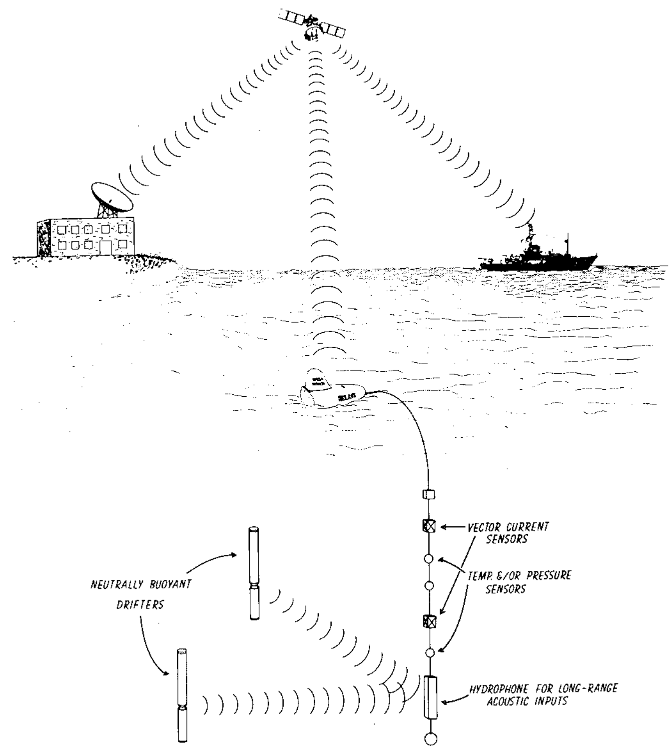
Robert R.P. Chase

The application of the myriad of technical innovations developed during the past decade to large scale oceanographic questions cannot be either scientifically or fiscally effective without a significant planning effort. Numerous conferences have been held throughout the worldwide research community to address this issue, resulting in a broad consensus that the technology now available is sufficiently well-developed that its application to large-scale, low frequency physical oceanographic problems is indeed within the realm of feasibility. We have therefore begun, with funding from the National Aeronautics and Space Administration and the Office of Naval Research, a major developmental initiative to bring to fruition the next generation of measurement systems.

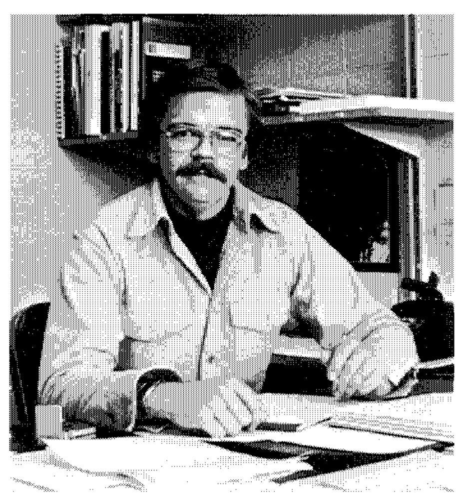
To be responsive to a broad class of research questions, we have applied an integrated systems approach to oceanic measurement problems. In doing so, we rely upon proven and productive technologies, exploiting those newly available innovations to their fullest. The result is a tripartite oceanographic observing system, capable of making measurements in all three spatial dimensions and through time, yielding a four-dimensional picture of the ocean on scales from days and a few tens of kilometers to years and the entire width of an ocean basin.

The tripartite oceanographic observing system under development consists of surface drifters and moorings, and remote sensing instrumentation. It rests upon a cornerstone of NASA-developed spacecraft capabilities, utilizing the proven capabilities of satellites to provide both significant new information about the ocean and relay more conventional in situ data directly to a researcher at time of acquisition. Drifter, mooring, and remote sensing data are closely matched in space and time, enabling the ocean's full four-dimensional structure to be analyzed. All data are telemetered to specially designed shoreside facilities for processing.

Unlike other measurement techniques, remote sensing is singular in its ability to provide continuous coverage over a large area, opening the possibility that significant new research can be performed and addressing a suite of oceanographic problems which previously could not be investigated. Existing satellite-borne instrumentation provides a variety of quantitative measurements such as sea surface temperature and surface pressure fields, thence surface geostrophic velocities. Other scientifically useful measurements include surface wind stress or driving force, wave height, chlorophyll content, and ice cover. Although the oceans are a dynamic fluid system responding in all three spatial dimensions and throughout time, satellite remote sensing is limited to measurements at the surface of the ocean. Consequently, a realistic approach to studying meso- to large-scale phenomena requires a combination of measurement techniques to monitor the full spatial and temporal extent of these phenomena. The satellite-based, tripartite oceano-



Schematic of the RELAYS system, part of the tripartite observing system. Below: Bob Chase.



Anne Rabushka

graphic observing system is the first attempt of its kind to provide these data.

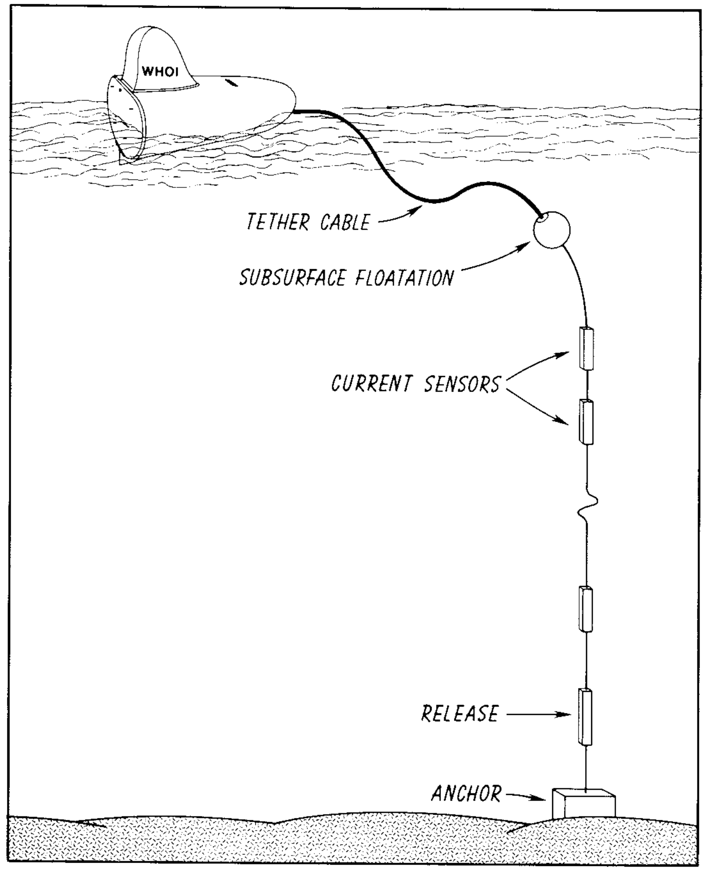
Part of this system is the Real-Time Link and Acquisition Yare System (RELAYS), which can be considered both a "floating mooring" and a "drifting autonomous listing station". It is a surface drifter capable of reaching into the interior of the ocean and telemetering data from various depths to shoreside facilities. RELAYS is a general purpose data acquisition platform uniting two proven measurement technologies into a single instrument platform capable of simultaneously transmitting all acquired data via satellite to any number of investigators at multiple locations through the world.

RELAYS consists of a surface torpedo buoy with data processing computer, satellite telemetry transmitter, rechargeable batteries and solar panel power supplies, and a subsurface electromechanical cable. Along the cable are placed current meters, pressure and temperature sensors, conductivity sensors, a hydrophone array and receiver, inclination and tension sensors, and distributed drag elements and flotation, forming the floating mooring concept. The hydrophone array and receiver provide an autonomous listening station capable of receiving and retransmitting both ambient environmental noise or acoustically transmitted data from tomographic sources or tracking and retransmitting data from freely-drifting, subsurface floats. This simple system has the advantage of potentially supporting many other types of measurements, thereby providing a very powerful yet routine link between the research scientist and the subsurface ocean.

The inclusion of current sensors on the RELAYS drifter, together with a satellite's ability to geographically track and position the platform provides, for the first time, a means of calibrating the performance of drifters and measuring the absolute current velocity of the upper ocean. Data derived either from cable-connected sensors or acoustically through the hydrophone is sampled serially by the microprocessor controller. This computer first processes the data onboard then waits until one of two polar-orbiting spacecraft is within the field-of-view; the data are then transmitted via radio to the satellite for distribution. Designed for air or ship-of-opportunity deployment, and with automated sensor check-out and calibration, the expense of operating the multifunctional platform is significantly less than the systems it replaces.

The satellite-linked oceanographic instrument system combines the best features of two proven and productive instrument systems; the subsurface mooring with its ability to sample a broad spectrum of parameters throughout most of the water column, and the surface telemetry link capable of transmitting data from all sensors on the"mooring string" to an investigator, immediately upon acquisition.

Designed to replace the WHOI standard intermediate mooring, microprocessor-based electronics housed within the RELAYS subsurface flotation sphere and powered by solar cells interrogate serially each of the sensors within the system, process these data, and then transmit the data over a radio-link to an operational satellite system. As presently configured, the satellite-linked system employs the same generic suite of sensors and electronics used within the RELAYS data acquisition platform.



Anchored mooring offers another dimension to the tripartite observing system.

Should failure occur in the surface tether cable, an emergency location transmitter within the surface buoy and a data recorder within the flotation sphere are activated. Thus, neither instrumentation nor data will be lost with this newly emerging system. With a design endurance of five years and automated sensor check-out and calibration, the expense of operating this mooring for long endurance experiments will be substantially less than existing systems.

Taken together, in situ and remote sensing data derived through this satellite-based tripartite oceanographic observing system provide the nucleus of a fruitful, cost effective, next generation observing system.

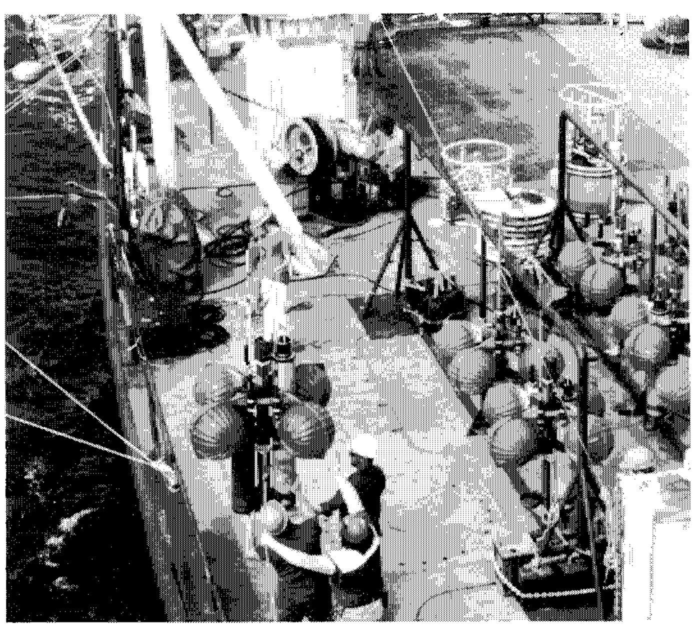
Ocean Bottom Hydrophones

G.M. Purdy

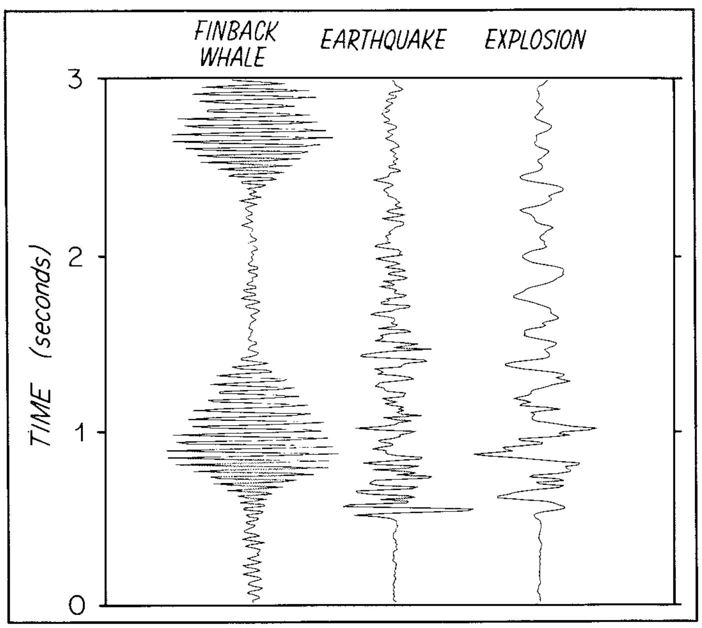
For the past seven years we have been using hydrophones positioned on the ocean bottom to listen to sounds both natural and man-made that tell us about the structure and ongoing processes deep inside the earth beneath the oceans. We have deployed instruments in over a hundred different locations in the Atlantic and Pacific Oceans and have intentionally, and sometimes by chance, recorded sounds ranging from the vocalizations of finback whales to earthquakes, airguns, and the explosions of tons of TNT (figure bottom right).

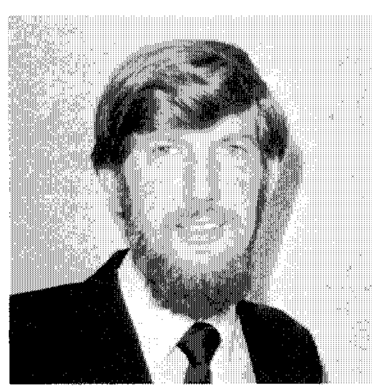
The study of seismic waves is one of the most powerful tools available to the marine geophysicist in his quest for knowledge about the earth's deep interior. These studies involve either the interpretation of man-made explosions in terms of the seismic velocity structure of the crust and mantle through which the seismic waves have propagated, or alternatively the study of earthquake sources to determine the nature of faulting associated with the release of tectonic stress. Although many seismic experiments are commonly carried out using hydrophones at the sea surface towed astern of a research vessel, there is often a need for monitoring incoming seismic energy either at a precisely fixed location or for a long period of time, or both. It is for these experiments that we have designed and built self-contained internally recording instruments to rest on or near the sea floor, record the output of a hydrophone, and return to the surface upon acoustic command from the research vessel. The duration of the deployment varies, depending upon the goal of the experiment, from a few hours to several weeks; we anticipate deployments of as long as one year in the future.

James Broda



The design of ocean bottom hydrophone instruments is complicated by the requirement for a high degree of reliability combined with the considerable versatility demanded by the widely differing requirements of a typical suite of seismic experiments. The necessity of reliability results from the high cost and complexity of modern seismic experiments in the deep ocean. Although it is conceivable that fairly economical instruments can be constructed so that the loss of one or two units becomes an acceptable risk, the resulting loss of data detracts so extensively from the success of the experiment as to be unacceptable. These considerations were paramount in our thinking when our first ocean bottom hydrophone instrument was designed and built in 1976 by technical staff members Donald Koelsch, Warren Witzell and Carlton Grant, Jr. We built an instrument oriented specifically towards the requirements of explosion seismic refraction experiments and were ruthless in our quest for both simplicity in design and for components and mechanical configurations that had been well proven by other scientists and





Shelley Lauzon

Above: Sounds recorded by the OBH. Far left: OBH deployment. Left: Mike Purdy.

Reports on Research

engineers at WHOI. The instrument (figure bottom right) consists of two independent pressure cases: one containing hydrophone recording electronics and the other an unmodified commercially available acoustic transponder release. Buoyancy capable of withstanding pressures of up to 10,000 pounds per square inch (equivalent to about 6,500 meters depth) is provided by four glass balls and the anchor weight is suspended beneath the acoustic release hook on about 10 feet of rope.

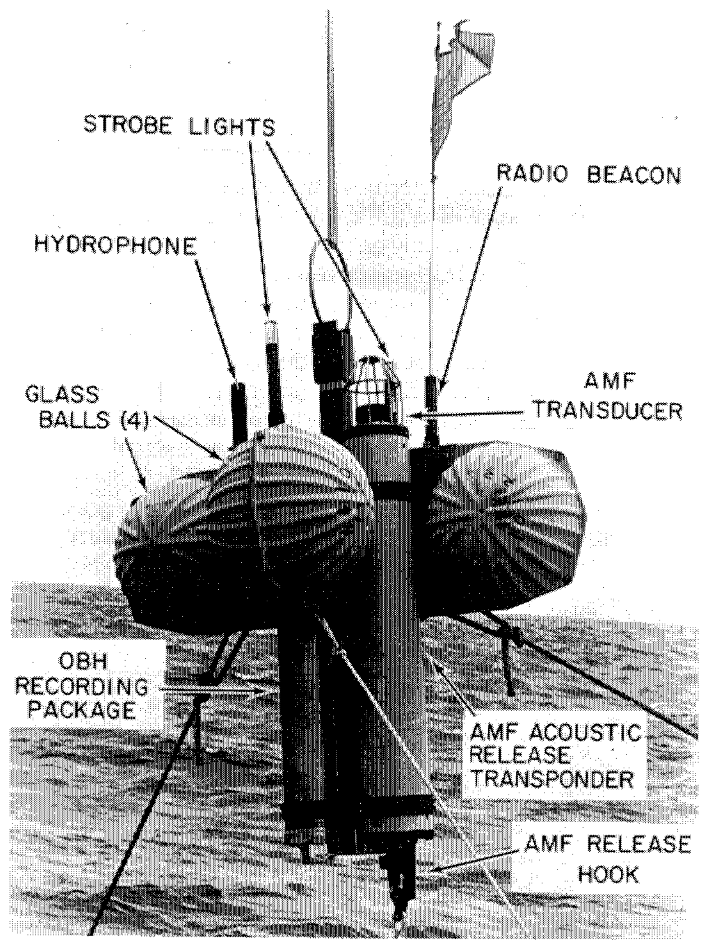
The hydrophone recording electronics consists of amplifiers, a crystal controlled chronometer and a slow speed direct recording ¼" tape recorder that operates at only 1⁄40 inch per second. A single 1,800-foot-long five-inch diameter reel of ½-millimeter-thick tape will thus provide a continuous recording of the hydrophone output for as long as 10 days.

This simple and reliable instrument has been the basis of almost all our data collection for the past seven years. However, as the complexity of our seismological experiments increases, the capabilities of this analog instrument become inadequate. The principal limitations lie in its limited bandwidth, limited dynamic range, and restricted recording duration.

To correct these deficiencies we have built a microprocessor controlled digitally recording instrument that shares the identical mechanical configuration with the analog version but has a more complex and flexible set of electronics. This new system with two microprocessors will be capable of remaining on the ocean floor for periods of many months recording high fidelity data. During one deployment the instrument can be programmed to change sampling rates, mode of operation, or both. After completion of a seismic refraction experiment recorded in preprogrammed mode, for example, the instrument could switch to event detect operation to record earthquakes or other random events. During a single experiment the nature of the source may change, and the sampling rate at which the data is recorded may have to be altered.

To ensure a reasonable distribution of data during a long earthquake monitoring experiment, a limit can be placed on the maximum number of events recorded per day to prevent filling the tape cartridge in one short period of time due to a localized swarm of events. The flexibility provided by the software eliminates the need for hardware modification; if sufficient care is taken in the initial preparation of the software, considerable reliability is gained from never having to modify the electronics at sea. As a result, we plan to operate the instrument in 'sealed-case' mode. Data retrieval, reprogramming, and check-out procedures can all be carried out from outside the instrument pressure case; only a component failure will necessitate opening the instrument at sea.

Our knowledge of the deep structure of the earth and of the processes that shape the major features of its surface and drive the lithosphere plates on their wandering paths around the globe is wholly inadequate. The oceans, lying on thin, relatively homogeneous crust, provide the geophysicist and seismologist with a window into the earth's interior that is not cracked and frosted by the mountain ranges and inhomogeneities that characterize the much thicker continents. To make full use of this 'window', ocean floor monitoring systems like our ocean bottom hydrophones are but a small beginning. More extensive and permanent installations will inevitably prove necessary. Our community has just begun to take advantage of the veritable treasure trove of data that lies waiting to be recorded on the ocean floor. Based on what little we have seen, it is certain that the next ten years of seismology in the deep ocean holds in store many exciting new breakthroughs in the fundamental understanding of the earth.



The ocean bottom hydrophone.

1983 Degree Recipients

Massachusetts Institute of Technology/ Woods Hole Oceanographic Institution Joint Program in Oceanography/ Oceanographic Engineering

Doctor of Philosophy

BRUCE D. CORNUELLE
B.A. Pomona College
Special Field: Physical Oceanography
Dissertation: *Inverse Methods and Results from the 1981 Ocean Acoustic Tomography Experiment*

MARGARET L. DELANEY
B.S. Yale University
Special Field: Chemical Oceanography
Dissertation: *Foraminiferal Trace Elements: Uptake, Diagenesis, and 100 m.y. Paleochemical History*

WILLIAM K. DEWAR
B.S. Ohio State University
Special Field: Physical Oceanography
Dissertation: *Atmospheric Interactions with Gulf Stream Rings*

ALAN V. KLOTZ
B.A. Rice University
Special Field: Biological Oceanography
Dissertation: *Purification and Characterization of the Hepatic Microsomal Monooxygenase System from the Coastal Marine Fish* Stenotomus chrysops

SUSAN M. LIBES
B.A. Douglas College
Special Field: Chemical Oceanography
Dissertation: *Stable Isotope Geochemistry of Nitrogen in Marine Particulates*

STEPHEN D. MCCORMICK
B.S. Bates College
Special Field: Biological Oceanography
Dissertation: *Effects of Size, Age and Photoperiod on Hypoosmoregulation in Brook Trout* Salvelinus fontinalis

KENNETH G. MILLER
A.B. Rutgers University
Special Field: Marine Geology
Dissertation: *Late Paleogene (Eocene to Oligocene) Paleoceanography of the Northern North Atlantic*

DOUGLAS R. MOOK
B.S., S.M. Massachusetts Institute of Technology
Special Field: Oceanographic Engineering
Dissertation: *The Numerical Synthesis and Inversion of Acoustic Fields Using the Hankel Transform with Applications to the Estimation of the Plane Wave Reflection Coefficient of the Ocean Bottom.*

CHRISTOPHER PAOLA
B.S. Lehigh University
Special Field: Marine Geology
Dissertation: *Flow and Skin Friction over Natural Rough Beds*

KRISTIN M. M. ROHR
B.A. Brown University
Special Field: Marine Geophysics
Dissertation: *A Study of the Seismic Structure of Upper Oceanic Crust Using Wide-Angle Reflections*

VICTOR ZLOTNICKI
Surveyor, Geophysics Engineer University of Buenos Aires, Argentina
Special Field: Marine Geophysics
Dissertation: *The Oceanographic and Geoidal Components of Sea Surface Topography*

Doctor of Science

GREGORY L. DUCKWORTH
B.S. Rice University
S.M. and E.E. Massachusetts Institute of Technology
Special Field: Oceanographic Engineering
Dissertation: *Processing and Inversion of Arctic Ocean Refraction Data*

SCOTT M. GLENN
B.S. University of Rochester
Special Field: Oceanographic Engineering
Dissertation: *A Continental Shelf Bottom Boundary Layer Model: The Effects of Waves, Currents, and a Moveable Bed*

JOHN H. TROWBRIDGE
B.S.C.E. University of Washington
Special Field: Oceanographic Engineering
Dissertation: *Wave-Induced Turbulent Flow Near a Rough Bed: Implications of the Time-Varying Eddy Viscosity*

Degree of Civil Engineer

WILLIAM J. BURKE
B.S.C.E. University of Notre Dame
Special Field: Oceanographic Engineering
Dissertation: *An Improved Loran-C Drifting Buoy and Drogue for Coastal Applications*

Shelley Lauzon

Shelley Lauzon

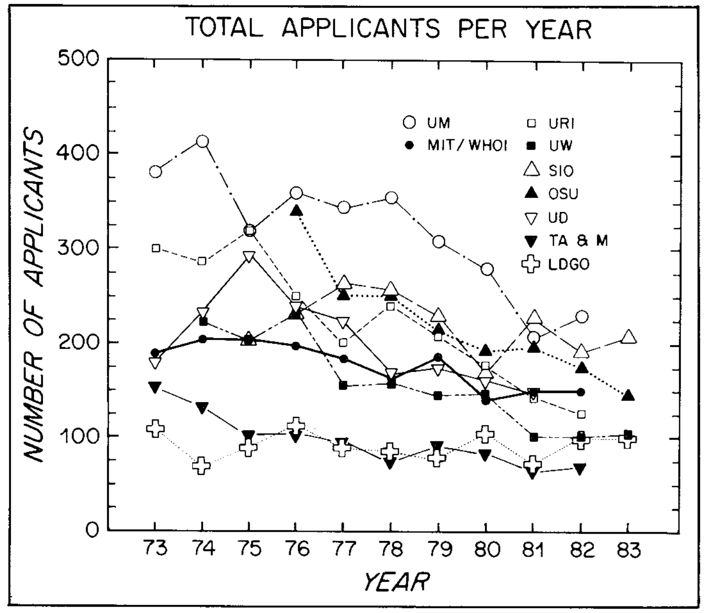
Left: Dave Aubrey lectures on coastal erosion in Clark 507. Above: Joint Program student Maureen Kennelly.

Dean's Comments

Record Number of Graduate Students

For the first time since the WHOI/MIT Joint Program was founded 17 years ago, our resident student body has climbed above the 100 mark. Our 1983 fall enrollment was a record 106.

When I became dean three years ago, there were 79 students in the program. At that time we set an enrollment goal of 110 within 5 years, without sacrificing the quality of our program. Active recruiting by our staff has helped us approach this goal. In order to maintain our exceptional quality level, however, we must continue to reach out for new student applicants from schools that have not sent us applicants.



Another Record

Our increased enrollment is also due in part to a significant rise in the Joint Program's acceptance rate. We've enjoyed a 10-year acceptance percentage average of 67% – the highest rate among all major oceanographic institutions. In 1983 our annual acceptance rate increased significantly, with 77% of applicants offered admission in 1983 enrolling in the program, a figure at least 25% higher than our competition's rate. Clearly, the Joint Program has become a premier choice for oceanographers of the future.

New MIT Joint Program Director

Arthur Baggeroer has been appointed the new MIT director of the Joint Program, filling the post vacated by Professor John Sclater who moved to the University of Texas. Arthur holds joint appointments in the departments of Ocean Engineering and Electrical Engineering and he has supervised numerous Joint Program graduates. He is also involved in a large joint MIT/WHOI research project in the Arctic.

Careers Booklet

Hot off the press – as we said it would be in last year's annual report – is the Careers in Oceanography booklet. The American Geophysical Union has printed 10,000 copies for distribution to science teachers, counselors, and prospective applicants to the graduate field of oceanography.

The booklet's first distribution target will be the National Science Teachers Association. We have identified the NSTA, which includes some 40,000 members, as the key vehicle for spreading the word that oceanography can be a fascinating career for the science major – a concept that seems to be virtually unknown amongst the tens of thousands of science-oriented undergraduates. Our recruiting efforts will be focused within this organization.

Deans' Retreat

The University of Washington hosted the third meeting of U.S. and Canadian Graduate Deans of Oceanography in June 1983. The Deans' Retreat, a forum started by WHOI in 1980, was attended by representatives from the University of Washington and WHOI as well as the University of British Columbia, Dalhousie University, University of Delaware, University of Hawaii, Lamont-Doherty Geological Observatory, University of Maryland, Oregon State University, University of Rhode Island, Scripps Institution of Oceanography, and Texas A&M University.

Some conclusions drawn at this meeting:

Despite decreasing numbers of applicants (see graph), the quality of applicants in general to these graduate schools has remained high. The largest pool of excellent applicants is in biological oceanography, but acceptances are funding-limited. The other disciplines are applicant-limited.

Oceanographic institutions use a shotgun approach to recruiting and seldom know whether their individual efforts are successful. The total applicant pool appears to number about 600; a 15-20% increase in that figure would have a significant impact.

Of questionable value in recruiting are flyers and brochures and advertisements placed in such publications as EOS or college newspapers. What may be of value are summer fellowship programs, personal recruiting trips by faculty to undergraduate schools for discussions, and visits by graduate students to their undergraduate institutions or local universities.

JOI, Inc. has agreed to act as an organizational body to help the deans' group and will provide support for future meetings. The next Deans' Retreat is slated for the fall of 1984 at Scripps.

An executive committee has been formed to coordinate future retreats and carry out recommendations of the body. Members of the committee include: Charles D. Hollister, Chair, and A. Lawrence Peirson III, Executive Secretary, both of WHOI: D. James Baker, JOI, Inc.; Richard Sternberg, University of Washington; and Ferris Webster, University of Delaware.

Ashore & Afloat

A capacity crowd was on hand 3 January in Redfield Auditorium to hear Vice President of General Motors Research Laboratories Robert A. Frosch deliver the fifteenth J. Seward Johnson Lecture in Marine Policy entitled "Relevance, Irrelevance and General Confusion: Problems in Science Policy." Frosch, a Trustee and former Associate Director for Applied Oceanography at the Institution, told the audience that despite problems the present U.S. science policy was better for science and technology than the rigidity of a tightly coordinated science policy some have proposed.

A $1.1 million two-year grant from The Pew Memorial Trust was received in January to establish an Ocean Engineering Research Laboratory ($400,000) and for continued support of the Marine Policy and Ocean Management Program ($700,000).

Massachusetts Secretary of Environmental Affairs James Hoyte visited Woods Hole 18 February to participate in Black History Month. During his visit he spoke to a large crowd in Redfield Auditorium on the state purchase of Washburn Island, the proposed waste facility at Otis Air Force Base, and the future of development on Cape Cod as it relates to ground water supplies.

A $1,000 college scholarship was awarded to Falmouth High School junior Sheila Clifford for her project on "Oil, *Artemia,* and Lipids" at the Falmouth Science Fair 12 March. Sheila is the daughter of Chemistry Department Research Associate Hovey Clifford.

Approximately 115 Associates and guests attended the annual spring dinner 26 April at the Boston Museum of Science. Three poster sessions on color computer graphics in oceanography, satellite-linked oceanographic observing systems, and shear strength of sediments were featured during the cocktail hour. Capt. Robertson P. Dinsmore spoke after dinner on "Oceanographic Ships, Past and Present." Two days later, 75 Associates and guests gathered at the University Club in New York to hear Senior Scientist Robert D. Ballard speak on "Argo/Jason, Woods Hole's New Exploration Vehicle."

Fourteen doctorates and one oceanographic engineering degree were awarded in the MIT/WHOI Joint Program in 1983, bringing the total number of degrees awarded since the program was founded in 1968 to 132 doctorates and 21 engineers degrees. Three WHOI degrees have also been awarded, for a total of 156 degrees. The 1983 entering class consisted of 25 students, including 12 women and three foreign students. Thirty-two were offered admission, making this year's acceptance rate of 78 percent the highest ever; the 10-year average has been 64 percent.

Inclement weather 27 May didn't dampen the spirits of some 35 new Associates and guests who visited the Institution for a closer look at facilities and an opportunity to learn more about our programs.

The Summer Geophysical Fluid Dynamics Program began its 25th consecutive year of operation in June with 11 Fellows and visiting lecturers and staff from the U.S. and abroad. Two Fellows attended from the Soviet Union.

Annual Meeting activities began 23 June as Trustees assembled for a meeting and dinner prior to the Annual Meeting. The following day, 68 Corporation Members and Trustees attended the Annual Meetings. Senior Scientist Robert C. Spindel presented the science report on acoustic tomography. Highlighting the activities was the dedication 24 June of the Advanced Chemistry Laboratory to Paul M. Fye, President of the Corporation since 1961 and Director of the Institution from 1958 to 1977. Several hundred, including many employees, gathered in front of the new Paul M. Fye Laboratory for the dedication ceremonies during the afternoon and had an opportunity to visit the facility during an Open House which followed. A large crowd gathered later in the day for the Associates lecture, presented by Senior Scientist John W. Farrington on "Organic Compounds and the Oceans: From Plankton to Petroleum and Back." Three hundred-thirty attended the combined Trustees, Corporation Members and Associates Dinner held that evening under a tent on the Fenno House grounds.

Shelley Lauzon

Dedication of the Paul M. Fye Laboratory.

Ashore & Afloat

Some 150 family members, friends and former colleagues gathered 25 June in Redfield Auditorium to pay tribute to Senior Oceanographer Emeritus Alfred C. Redfield, who passed away 17 March at age 92. Director John H. Steele joined others from the scientific community in remembering his contributions, and family members offered their recollections.

Redfield Auditorium was filled to capacity 27 June for the sixteenth J. Seward Johnson Lecture in Marine Policy, "The Future of Ocean Science," presented by Roger Revelle. A WHOI Trustee and former Director of the Scripps Institution of Oceanography, Revelle is Professor of Science and Public Policy at the University of California, San Diego. He outlined the advances we have made in ocean science and the challenges which lay ahead, and stressed the importance of attracting and retaining bright young scientists in marine science.

A $200,000 challenge grant was received in July from The Kresge Foundation toward construction costs of the Paul M. Fye Laboratory.

Members of the Ocean Engineering Department donated their time and use of the Institution's recently purchased remotely piloted vehicle (RPV) to assist the Quincy (MA) Fire Department in searching for the body of a 17-year-old youth who jumped from a ledge in Swingle's Quarry in that city. After four full days of operation and more than 10 dives into the 400-foot-deep quarry, the unsuccessful search was called off by mutual decision.

The MBL Library, jointly funded and operated by the Institution and the Marine Biological Laboratory, was awarded a $1 million challenge grant from The Andrew W. Mellon Foundation. The grant, to be matched by $1.5 million from other sources in the next few years, will provide endowment revenues for space and equipment improvement, staff development and training, and other needs.

Hoyt Watson

American defender *Liberty* passes by the stern of *Oceanus* during a postponement in the first America's Cup race 13 September.

Twenty entries competed in the fourth annual Anything But a Boat Regatta 7 August in Great Harbor. More than 1,000 watched the event. That afternoon, several hundred employees and their families gathered on the Fenno House grounds for the annual Employee Picnic. A ten-piece jazz band provided musical entertainment.

Massachusetts Governor Michael S. Dukakis visited the Institution 12 August for briefings on coastal erosion, research important to fisheries, and acid rain on Cape Cod. The Governor, Secretary for Economic Development and Manpower Affairs Evelyn Murphy, Director John H. Steele and representatives from local marine-related industries met to discuss ways in which the state government could assist both research and industrial organizations in southeastern Massachusetts. Dukakis expressed hope Woods Hole would become the marine-related high technology center for excellence.

One hundred Associates and guests were entertained by four humpback whales and a calf during a whale watch expedition 9 September off Provincetown aboard the charter vessel *Dolphin IV*. A school of white-sided porpoises, two finback whales and a shark were also sighted.

On 13 September more than 520 Associates and guests aboard *Oceanus* and the charter vessel *Point Gammon* traveled to Rhode Island Sound off Newport to watch the first race for the America's Cup. After two unsuccessful attempts to set the course, the race was postponed, but spectators got a close-up look at American defender *Liberty* and challenger (and eventual winner) *Australia II*.

Senior Scientist Henry M. Stommel was chosen one of two recipients of the 1983 Crafoord Prize for his "fundamental contributions in the field of geophysical hydrodynamics that in a unique way contributed to our understanding of the large-scale circulation of the atmosphere and the sea." The Crafoord Prize is presented by the Royal Swedish Academy of Sciences, which awards the Nobel Prizes.

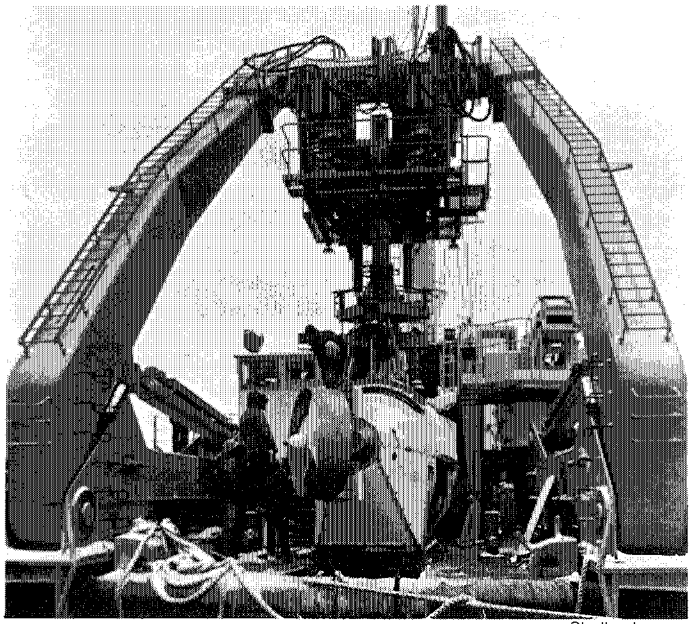
Senior Scientist Robert D. Ballard was featured in a National Geographic Society special on plate tectonics, "Born of Fire," which aired 6 April on the Public Broadcasting System network.

Senior Scientist Howard L. Sanders was one of 60 new members elected to the National Academy of Sciences.

Associate Scientist John A. Whitehead, Jr., was elected a Fellow of the American Physical Society.

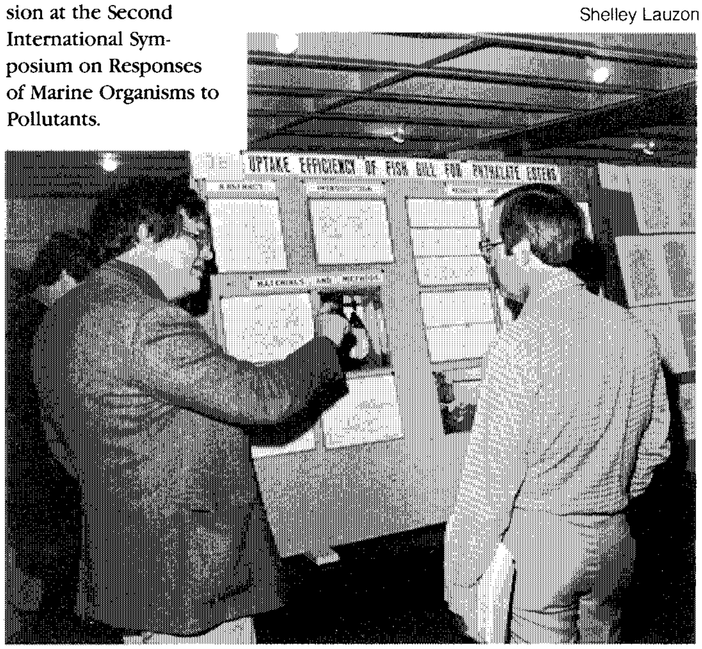
Scientist Emeritus Robert W. Morse was one of 296 individuals elected Fellows of the American Association for the Advancement of Science.

Senior Scientist Peter G. Brewer received the National Science Foundation's (NSF) Sustained Superior Performance Award in recognition of his two years at NSF as manager of the marine chemistry program.



Shelley Lauzon

Shelley Lauzon



Top: Work continued in December on the *Alvin* hoist system. Middle: Peter Brewer (right) receives the National Science Foundation's Sustained Superior Performance Award from M. Grant Gross, Ocean Science Division director. Bottom: Poster session at the Second International Symposium on Responses of Marine Organisms to Pollutants.

Associate Scientist William J. Jenkins was selected the recipient of the 1983 Rosenstiel Award in Oceanographic Science for his "contributions to the measurement of time scales of ocean processes and for insights he has provided to oceanic circulation and seafloor formation." The Rosenstiel Award, $5,000 and a medal, was presented to Jenkins 10 November in Miami.

Analytical Geochemist Jean K. Whelan became the Institution's first woman senior research specialist in August. She has been at WHOI 10 years.

DSRV *Alvin* began a five-month overhaul and maintenance period following its return to Woods Hole 17 December 1982 aboard R/V *Lulu*. During the overhaul the submersible's titanium frame was extensively modified to accommodate the single-point lift system being installed on R/V *Atlantis II*. *Alvin* and *Lulu* returned to service in late June for a series of summer dives in the North Atlantic for biological, geological, and engineering studies. The pair ended their historic partnership of nearly 20 years when the submersible was transferred to *Atlantis II* in November. *Lulu* remained at the pier with a skeleton crew through the end of the year waiting for word from the U.S. Navy as to her future use.

Work continued at pierside throughout 1983 on *Atlantis II* as part of the mid-life refit and overhaul begun in 1979. Conversion for the over-the-stern lift system for *Alvin* was done simultaneously, with installation of deck tracks and a hangar for the sub, nearby support shops in part of the main lab, and the 41-foot hydraulic A-frame and control shed on the fantail.

R/V *Oceanus* departed 10 January for a four and one-half month voyage to South America and Africa, the ship's longest voyage to date. *Oceanus* spent the rest of the year in and out of Woods Hole engaged in biological, chemical, physical oceanographic, and ocean engineering studies in the North Atlantic.

R/V *Knorr* was briefly powered by sails during Voyage #102 in May when the engines broke down several hundred miles south of Woods Hole. Tarps from the Bosun's locker were hung from the foremast and served for a little more than a day until the engines were repaired. The ship began the year engaged in work for the Tropical Atlantic Study, spent the summer in and out of Woods Hole for geological and ocean engineering studies in the western North Atlantic, and departed in mid-July for a 10-month cruise to the South Atlantic primarily for physical oceanographic and geophysical studies.

Among the many visitors to the Institution during the year were Professor Hsu Houtze of the Institute of Geodesy and Geophysics, Academy of Sciences, of the People's Republic of China and a group from the South China Institute of Oceanology. Twenty-five representatives from oil companies, engineering firms and local instrumentation manufacturers attended a two-day workshop in March on "Development in Coastal Ocean Dynamics: Small- and Large-Scale Processes"; the workshop was the first in an expanded Ocean Industries Program which now includes firms other than oil companies who work in or have an interest in the marine environment. Several hundred scientists gathered in Woods Hole in late April for the Second International Symposium on Responses of Marine Organisms to Pollutants, during which 90 papers were presented on the mechanisms and significance of pollutant effects in marine animals; Associate Scientist John J. Stegeman was symposium chairman. The Naval Command College of the Naval War College visited for the first time in May; 36 nations were represented. The Acoustical Society of America Narragansett Chapter held its June meeting at the Institution, with Associate Scientist George V. Frisk delivering the keynote address on "Ocean Bottom Acoustics." More than 100 members of the MIT Class of 1943 spent the day 11 June in Woods Hole to hear presentations about Institution research activities and facilities and the joint education program with MIT. Dr. Kemal Kafali, Rector of Istanbul University, discussed exchanges of technical and scientific information and cooperative activities during a visit 16 June. Two U.S. Congressmen visited the Institution in August; Rep. Robert Traxler (D-Michigan) of the House Appropriations Committee spoke with scientific staff members and toured facilities 23 August, while Sen. Robert Packwood (R-Oregon), chairman of the Committee on Commerce, Science and Transportation visited 30 August. An ad hoc group on Arctic Ocean Science of the National Academy of Sciences Polar Research Board met 26-27 at the Institution to develop a plan for Arctic marine science not presently being addressed; John H. Steele is a member of the committee. Seventy-five Stanford University alumni aboard a charter vessel spent 3-4 October in Woods Hole and heard presentations on Institution research and facilities. A working symposium on oceanographic data systems 4-6 October attracted 150 engineers and computer specialists to the Institution; Research Specialist Gus D. Tollios was program chairman. Seventy-five scientists, shellfish officers and commercial fishermen met 28 October at the Institution to discuss the biology, ecology, and management of the bay scallop. Two delegations of Japanese scientists and engineers interested in pollution and deep-sea mining visited during October. "Research Problems of Joint Utility Industry/WHOI Interests" was the topic of a workshop 16-17 November which attracted representatives from various electric research organizations and power companies. The Ocean Industries Program's Policy & Environmental Studies Section sponsored a seminar 7-8 December on "Ocean Policy and Economics and Our Use of the Sea."


Shelley Lauzon

Chief *Alvin* Pilot Ralph Hollis explains the launch system on *Lulu* to foreign officers attending the Naval War College staff course.

Friends, family members, and colleagues gathered 16 December for thirty-year pin presentations to William M. Dunkle, Jr., Paul M. Fye, Thomas D. Rennie, and Eloise M. Soderland. Ten individuals who retired during the year were also honored.

More than 300 employees and guests attended the annual Institution Christmas Party 17 December at the New Seabury Country Club.

The Institution's warehousing facilities were further centralized at year's end with the addition of a new warehouse in the GEOSECS area of the Quissett Campus. A 20-meter fiberglass flume for biological, chemical, and fluid dynamical studies was delivered to the Coastal Research Laboratory and expected to be in operation in the spring of 1984. The Office of the Research Librarian expanded its facilities in the first floor of Clark Laboratory by opening a reading room with a book collection for students.

Publications

1983 Publications of record as of 1 March 1984. Institution contribution number appears at end of each entry. 1982 publications not listed in 1982 Annual Report are included here; the date appears in parenthesis preceding the contribution number.

Biology

Anderson, D. M., S. W. Chisholm and C. J. Watras. Importance of life cycle events in the population dynamics of *Gonyaulax tamarensis*. *Mar. Biol.*, 76:179-189. 5201

Binder, B. J. and R. J. Naiman. Decomposition of paper birch and speckled alder leaf litter in a seawater environment. *Arch. Hydrobiol.*, 97(2):163-179. 4909

Binder, R. L. and J. J. Stegeman. Basal levels and induction of hepatic aryl hydrocarbon hydroxylase activity during embryonic period of development in brook trout. *Biochem. Pharmacol.*, 32(7):1324-1327. 5212

Black, G. A., W. L. Montgomery and F. G. Whoriskey. Abundance and distribution of *Salmincola edwardsii* (Copepoda) on anadromous brook trout, *Salvelinus fontinalis* in the Moisie River system, Quebec. *J. Fish Biol.*, 22(4):567-575. 5161

Brand, L. E., W. G. Sunda and R. R. L. Guillard. Limitation of marine phytoplankton reproductive rates by zinc, manganese and iron. *Limnol. Oceanogr.*, 28(6):1182-1198. 5088

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Hugh D. Livingston, Analytical Radiochemist,
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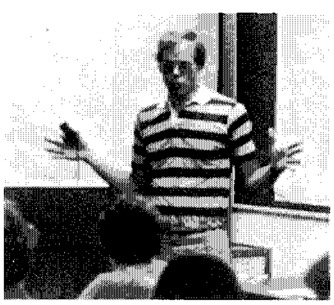

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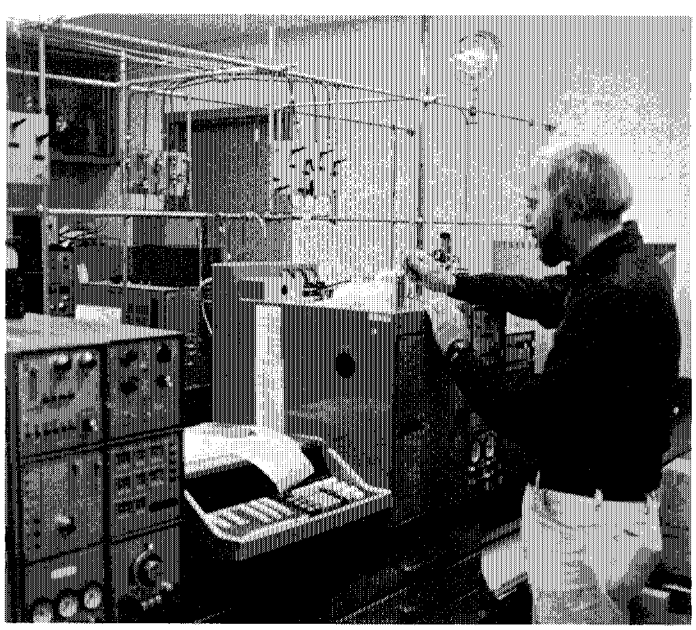

Above: Larry Madin gives a summer lecture. Right: Alan Davis sets up equipment after moving into the Fye Laboratory.

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Cliff Winget and summer employee Charles O'Brien work on a HEBBLE water tunnel in the Coastal Research Laboratory. Left: Loren Shure.

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Jurg K. Schneider (Chemistry)

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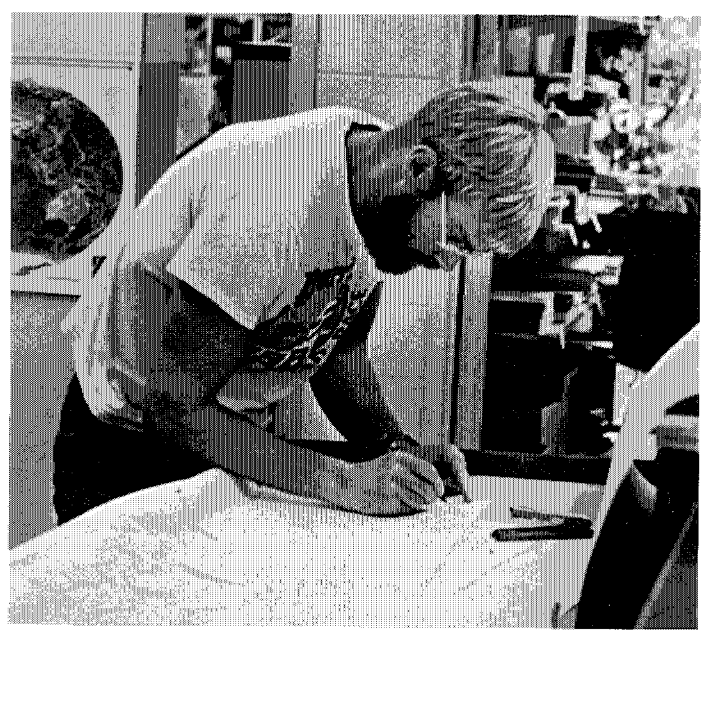
Bob Beardsley works on a chart.



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Steve Gegg digitizes an image at IPC.
Bottom: Cindy Lanyon.

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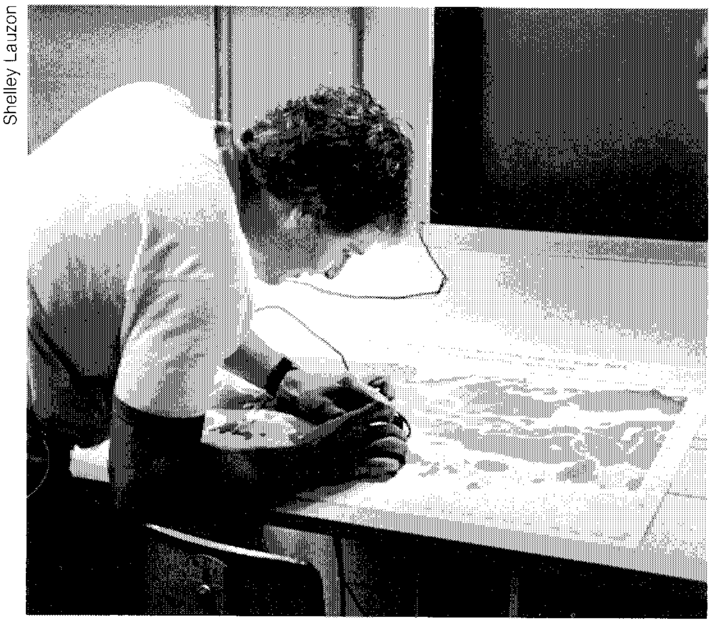

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Coastal Research Center

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Carpenter Chris Kennedy at work. Right: Diane Eskenasy prepares samples from the Georges Bank Sediment and Organism Monitoring Program.

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Rod Catanach


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Joseph Ribeiro
#Harry Rougas
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+William L. Sylvia, Jr.
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*Frank D. Tibbetts
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#Disability Leave of Absence
+Leave of Absence
*Deceased 13 February 1983

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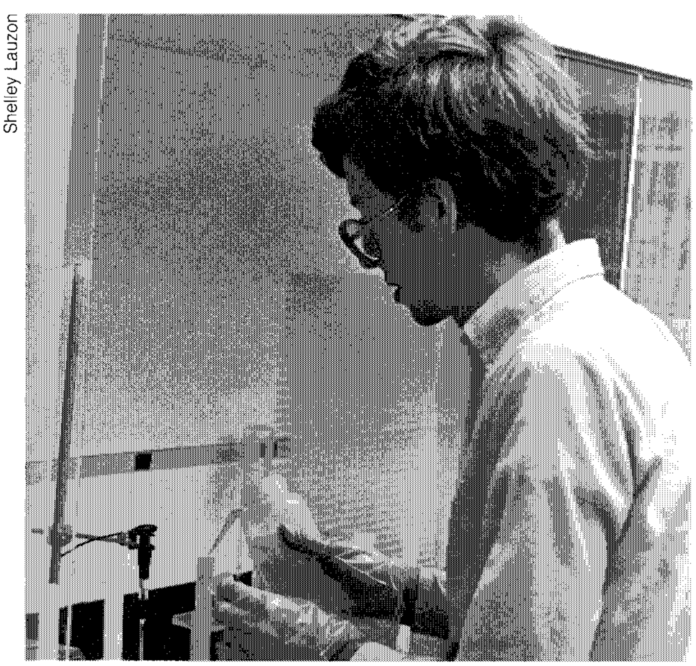
Left: Summer Student Fellow Carol Arnosti. Below: Joint Program student Hein DeBaar.

Shelley Lauzon



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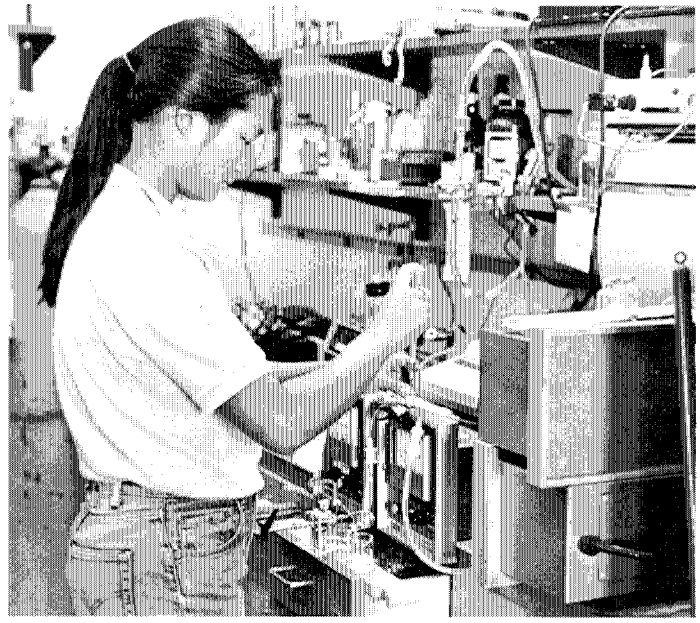

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Voyage Statistics

R/V *Atlantis II*

Voyage	*Cruise Period*	*Principal Objectives, Area of Operations*	*Ports of Call*	*Chief Scientist*
111	22 Jun-22 Jun	To shipyard	Boston	
111	10 Sep-10 Sep	From shipyard	Woods Hole	

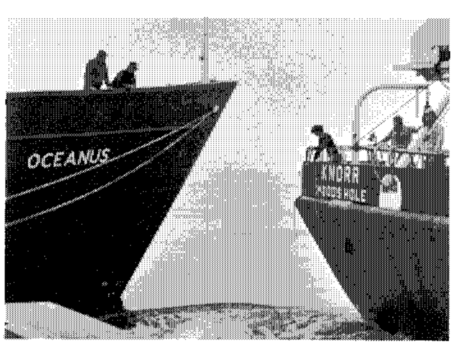
R/V *Atlantis II* remained at the pier in Woods Hole for the year undergoing maintenance and upgrading as part of the mid-life refit and overhaul begun in 1981 and for conversion for DSRV *Alvin* operations. Conversion included installation of a 39-foot hydraulic A-frame for an over-the-stern submersible handling system, a hangar on the fantail for *Alvin,* a new bow thruster for increased maneuverability, and transducers for the multi-beam echo sounding system Sea Beam.

R/V *Knorr*

Total Nautical Miles for 1983 – 34,991 miles
Total Days at Sea – 255 days

Voyage	*Cruise Period*	*Principal Objective, Area of Operations*	*Ports of Call (Destination)*	*Chief Scientist*
99-IV	29 Dec-24 Jan	Investigation of circulation and mixing processes in the tropical and equatorial Atlantic for the Tropical Atlantic Study	Dakar, Senegal	Rooth (Miami)
99-V	30 Jan-18 Feb	Continuation of the Tropical Atlantic Study	Recife, Brazil	Takahashi (LDGO)
99-VI	21 Feb-28 Feb	Chemical studies of the seasonal changes in sedimentation rates and composition in the western North Atlantic	Bridgetown, Barbados	Deuser
99-VI	1 Mar-12 Mar	Transit	Woods Hole	
100	15 Mar-16 Mar 7 Apr-8 Apr	To shipyard From shipyard	Jersey City, New Jersey Woods Hole	
101	15 Apr-25 Apr	Geological and ocean engineering studies at the High Energy Benthic Boundary Layer Experiment (HEBBLE) site to characterize the effects of the Western Boundary Undercurrent on the Nova Scotian Continental Rise	Woods Hole	Hollister
102	30 Apr-31 May	Geophysical studies on the Bermuda Rise to define the heat flow anomaly associated with the Rise	Woods Hole	Von Herzen
103	5 Jun-18 Jun	Continuation of geological and ocean engineering studies at the HEBBLE site	Woods Hole	Hollister
104-I	15 Jul-2 Aug	Hydrographic studies of the northwestern North Atlantic	Ponta Delgada, Azores	Raymer
104-II	6 Aug-26 Aug	Continuation of hydrographic studies of the central North Atlantic	Recife, Brazil	McCartney
104-III	2 Sep-30 Sep	Studies of the dynamic response of the upper equatorial Atlantic to seasonally varying surface winds for the SEQUAL program	Abidjan, Ivory Coast	Katz (LDGO)
104-IV	7 Oct-6 Nov	Hydrographic stations and data collection on the general circulation of the South Atlantic and Southern Oceans	Cape Town, South Africa	Reid (SIO)
104-V	13 Nov-12 Dec	Studies of the stratification and circulation of the Agulhas Current south of Africa	Cape Town, South Africa	Gordon (LDGO)

Left: *Knorr* joins *Oceanus* at the pier. Right: Christmas lights on *Atlantis II.*



Shelley Lauzon

Shelley Lauzon

Frank Medeiros

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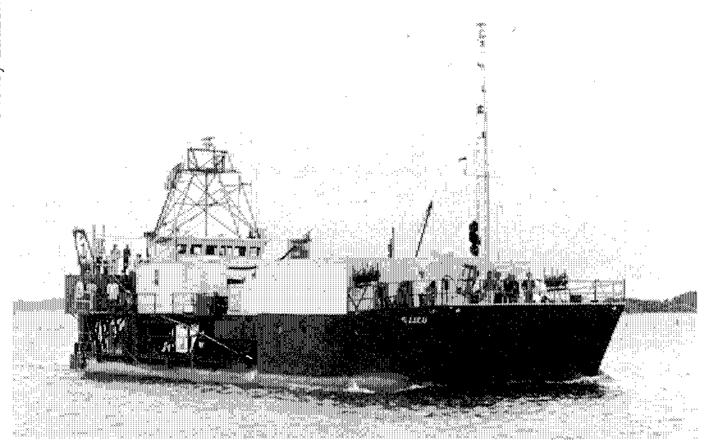

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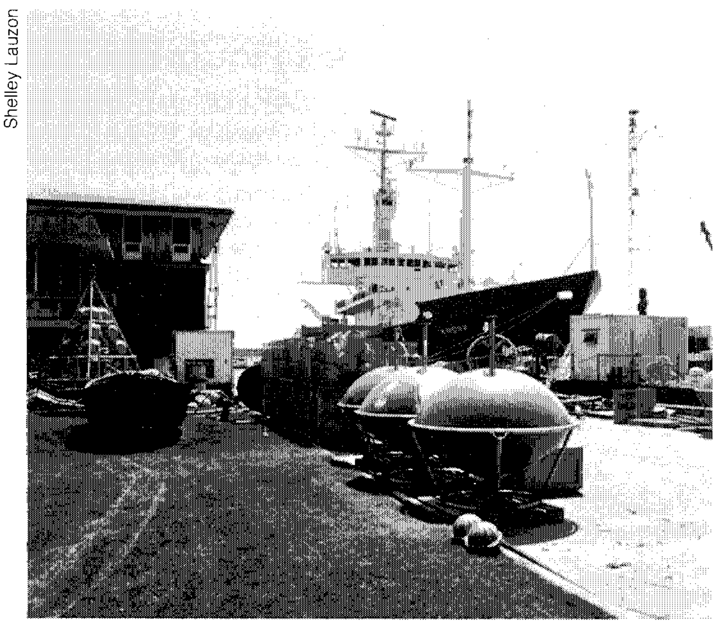


Above: *Atlantis II* in summer drydock for installation of a new bow thruster, Sea Beam transducers and routine hull maintenance. The observation chamber is visible on the bow. Top right: *Lulu* returns to port in August to complete her last voyage with *Alvin*. Bottom right: *Knorr* at the pier between voyages.

DSRV *Alvin* and R/V *Lulu*

Total Nautical Miles for 1983 – 2,342 miles
Total Days at Sea – 37 days
Total Dives – 28

Voyage	*Cruise Period*	*Principal Objectives, Area of Operations*	*Ports of Call (Destination)*	*Chief Scientist*
115	27 Jun-1 Jul	Three dives for submersible and pilot certification at Deep Ocean Stations #1 and #2 and off Gay Head	Woods Hole	Hollis
116	5 Jul-9 Jul	Two dives on Georges Bank and the Continental Slope for equipment tests and training	Woods Hole	Hollis
117	12 Jul-21 Jul	Six dives for biological studies of benthic communities at Deep Ocean Station #2	Woods Hole	Grassle
118	24 Jul-28 Jul	Three dives on the Continental Slope south of Martha's Vineyard for biological studies	Woods Hole	Wishner (URI)
119	2 Aug-12 Aug	Six dives for ocean engineering studies on the Continental Slope east of Boston	Woods Hole	Williams (KAPL)
120	17 Aug-17 Aug	One dive off Gay Head for equipment tests and training	Woods Hole	Walden

DSRV *Alvin* spent the first five and one-half months of 1983 undergoing annual maintenance and repair as well as conversion for the new handling system on R/V *Atlantis II*. The sub's titanium frame was modified and additional buoyancy added to meet the requirements of the new handling system. *Alvin* was transferred to *Atlantis II* 18 November; R/V *Lulu* remained at the pier at year's end awaiting word from the U.S. Navy as to her future use.

Voyage Statistics

R/V *Oceanus*

Total Nautical Miles for 1983 – 38,346 miles
Total Days at Sea – 230 days

Voyage	*Cruise Period*	*Principal Objectives, Area of Operations*	*Ports of Call (Destination)*	*Chief Scientist*
133-I	10 Jan-17 Jan	Recovery of a subsurface mooring and three transponders off the Florida coast	Bridgetown, Barbados	Boutin
133-II	19 Jan-30 Jan	CTD transect of the Western Basin of the North Atlantic from east of Barbados to the Mid-Atlantic Ridge	Recife, Brazil	McCartney
133-III	3 Feb-12 Feb	CTD transect of the South Atlantic	Rio de Janeiro, Brazil	Raymer
133-III	17 Feb-5 Mar	Continuation of CTD transect for studies in the central South Atlantic	Walvis Bay, Southwest Africa	Raymer
133-IV	10 Mar-2 Apr	Continuation of CTD transect of the South Atlantic	Recife, Brazil	Warren
133-V	10 Apr-24 Apr	Survey of the Brazil Current with combined XBT and Pegasus Profiler stations	Recife, Brazil	Evans (URI)
133-VI	27 Apr-20 May	North-south hydrographic section along the 52°W meridien in the western North Atlantic from 6°N to the Grand Banks of Newfoundland	Woods Hole	McCartney
134	14 Jun-12 Jul	Hydrographic stations to investigate the subthermocline circulation in the western North Atlantic	Woods Hole	Hogg
135	28 Jul-6 Aug	Deployment of three subsurface moorings and associated transponders for an acoustic tomography experiment, recovery of a subsurface mooring at the Long Term Upper Ocean Study (LOTUS) site at 34°N, 70°W	Woods Hole	Spindel
136-I	12 Aug-25 Aug	Diving, mid-water trawling, plankton net tows and hydrocasts to assess feeding behavior and energetics of planktonic gelatinous zooplankton	St. John's, Newfoundland	Madin
136-II	29 Aug-9 Sep	Coring and sample collection for microbial studies on the eastern Grand Banks and Carson Canyon area	Woods Hole	Jannasch
137	13 Sep-13 Sep	America's Cup Race in Rhode Island Sound	Woods Hole	
138	16 Sep-20 Sep	Geological and ocean engineering studies at the HEBBLE site on the Nova Scotian Continental Rise	Woods Hole	Hollister
139	26 Sep-5 Oct	Recovery of three subsurface moorings and associated transponders deployed on Voyage #135	Woods Hole	Spindel
140	17 Oct-24 Oct	Recovery and deployment of subsurface moorings, tripods, and surface buoys on the Continental Shelf and Slope south of Georges Bank	Woods Hole	Butman (USGS)
141-I	28 Oct-4 Nov	Recovery and deployment of two moorings at 34°N, 70°W for the LOTUS program, recovery of mooring near the Gulf Stream, CTD and XBT stations	St. George's, Bermuda	Briscoe
141-II	5 Nov-9 Nov	Recovery of a sediment trap mooring south of Bermuda	Woods Hole	Clay
142	11 Nov-19 Nov	Collection of sediment and biological samples for the Georges Bank Sediment and Organism Monitoring Program	Woods Hole	Petrecca
143-I	5 Dec-9 Dec	Testing traction winch system in the western North Atlantic	St. George's, Bermuda	Marquet
143-II	10 Dec-14 Dec	Recovery of a subsurface mooring 200 miles south of Bermuda	Woods Hole	Spindel

In Memoriam

Alfred C. Redfield
1890-1983

Alfred C. Redfield, one of the first to be appointed to the scientific staff when the Institution was founded in 1930 and an inspirational leader for five decades, passed away 17 March 1983 at age 92. A major figure in marine science and mentor to generations of biologists and physical oceanographers, Dr. Redfield was a naturalist who considered the ocean a vast organism in which biological, physical and chemical changes are clearly and intimately interrelated. His philosophy that "life in the sea cannot be understood without understanding the sea itself" is inscribed on the biology/chemistry laboratory in Woods Hole that bears his name.

An inquisitive and imaginative thinker, Alfred Redfield conducted pioneering investigations of the effects of ionizing radiation on biological processes and studies in comparative blood physiology of mammalian hemoglobin and invertebrate hemocyanin, the "blue blood" of the horseshoe crab. Work undertaken on marine fouling for the U. S. Navy during World War II led to publication of a text, "Marine Fouling and Its Prevention" which is still considered an authoritative review of the problem of organic growth on ship hulls. He was also interested in the circulation patterns in the Gulf of Maine and the drift, development and distribution of planktonic populations in that area, and contributed to physical oceanography through his investigations of tidal phenomena in narrow embayments and the circulation and flushing of harbors and estuaries. In his later years he probed the biology, chemistry, and physics of the salt marsh.

A graduate of Harvard University, he joined the faculty there in 1921 and in 1931 was named Professor of Physiology, serving from 1934 to 1938 as chairman of the Biology Department and as director of the Biological Laboratories. He began his long association with the Institution in 1930 when he was one of the first eight appointed to the staff of the new laboratory. For the next decade he devoted summers to research in Woods Hole while teaching at Harvard during the academic year. In 1942 he was appointed Associate Director of the Institution and he moved permanently to the village.

In addition to his scientific and administrative duties, he served as a Trustee from 1936 to 1963 and as a Member of the Corporation from 1936 to 1974, when he was named an Honorary Member. He also served on the Executive Committee from 1943 to 1955 and as Deputy Clerk in 1951-1952 and 1954-1955.

Dr. Redfield retired from both Harvard and the Institution in 1956. He continued to write and publish, and in 1980 was honored by the Institution upon his 90th birthday with publication of his last book, "The Tides of the Waters of New England and New York". He was active in town affairs in Falmouth, serving for many years on the Conservation Commission and as a town meeting member. He was a member of many scientific organizations including the National Academy of Sciences, which honored him with its Agassiz Medal in 1956 for his original contributions to oceanography, and was president of both the American Society of Limnology and Oceanography and the Ecological Society of America.

W. Van Alan Clark, Jr.

Founder of the Sippican Corporation and long-time friend and supporter of the Institution W. Van Alan Clark, Jr. died 16 July 1983 at age 63. Mr. Clark was elected a Member of the Corporation in 1964 and a Trustee in 1966, most recently serving a four-year term as Trustee from 1979 to 1982. He served on many committees including the Trustees Development Committee and as chairman of the Audit Committee. The son of Edna McConnell and W. Van Alan Clark, for whom Clark Laboratory is named, W. Van Alan Clark, Jr. served as assistant and associate professor and assistant dean at MIT's School of Industrial Management, leaving in 1958 to found the Sippican Corporation, manufacturer of oceanographic and energy instrumentation, which he served as President and Chairman of the Board. A highly regarded international cruising and racing sailor, W. Van Alan Clark, Jr. was also involved with numerous other organizations, serving as a Director of Avon Products and as Vice-President and Director of the Edna McConnell Foundation.

J. Seward Johnson

Long-time Institution benefactor, Trustee and Member of the Corporation J. Seward Johnson died 23 May 1983 at age 87. He became a life member of the Associates in 1957 and was elected a Member of the Corporation in 1959, a Trustee in 1961, Honorary Trustee in 1969 and Honorary Member in 1974. In 1969 Mr. Johnson made an $8 million gift to the Development Campaign, and made numerous gifts to the ships in the form of radar and navigation equipment. He was influential in establishing the Marine Policy and Ocean Management program, and through the generosity of the Atlantic Foundation enabled the Institution to purchase 95 acres in Quebec, Canada, to establish the Matamek Research Station. Mr. Johnson founded the Harbor Branch Foundation in Fort Pierce, Florida, in 1970.

Carroll L. Wilson

World-renowned scientist and management specialist Carroll L. Wilson, a Trustee and Member of the Corporation since 1963, passed away 12 January 1983 at age 72. He was involved in establishing the MIT/WHOI Joint Graduate Education Program and held a number of prominent positions in industry and government, including general manager of the U. S. Atomic Energy Commission. He was a professor at MIT's Sloan School of Management from 1959 to 1976.

Julian H. Gibbs

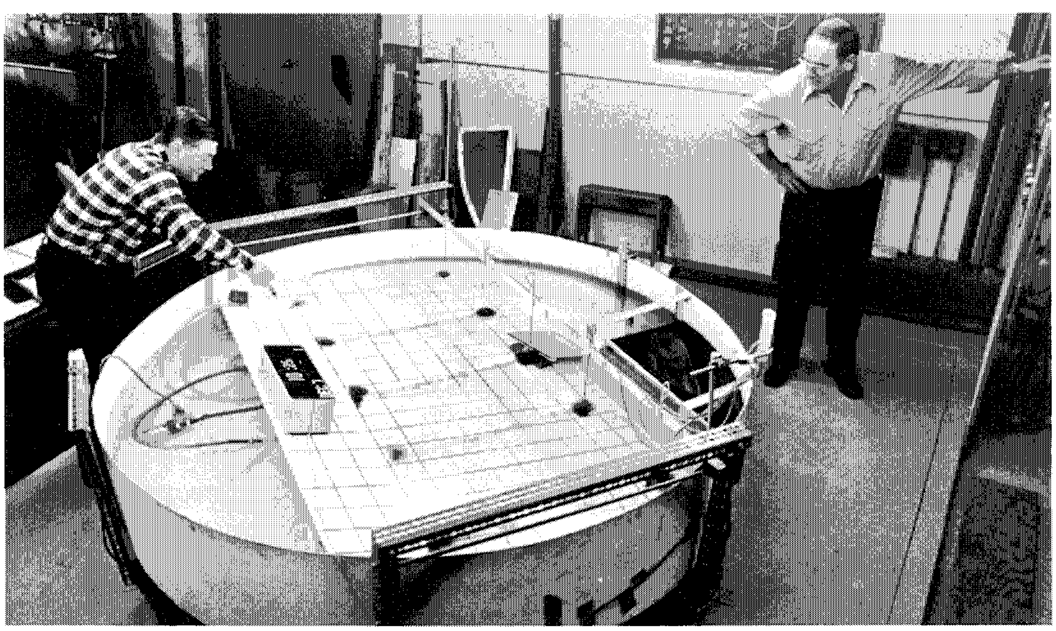
Amherst College President Julian H. Gibbs died 20 February 1983 at age 58. A respected chemist and a member of the Brown University faculty from 1960 to 1979, Dr. Gibbs left his post as chairman of the Chemistry Department at Brown to become the fifteenth president of his alma mater. He was elected a Member of the WHOI Corporation in 1981.

Robert M. Love

Honorary Corporation Member Robert M. Love passed away 9 October 1983 at age 74. Mr. Love began his career as an aircraft salesman, eventually becoming president and chairman of Allegheny Airlines. He was elected a Member of the Corporation in 1965 and was named an Honorary Member in 1974.

Trustees & Corporation

Anne Rabushka



Jack Whitehead (left) adds dye to a fluid dynamics experiment as Bob Frazel operates the overhead camera.

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San Francisco, CA

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Carnegie Institution of Washington
Washington, DC

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Fort Myers, FL

HOWARD W. JOHNSON
Massachusetts Institute of Technology
Cambridge, MA

Top left: Julie Andrade. Bottom left: Rick Chandler. Right: Dave Sanders.

Shelley Lauzon

Shelley Lauzon

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Falmouth, MA

RAYMOND B. MONTGOMERY
Woods Hole, MA

ROBERT S. MORISON, M.D.
Peterborough, NH

**Deceased 23 May 1983

***Deceased 9 October 1983

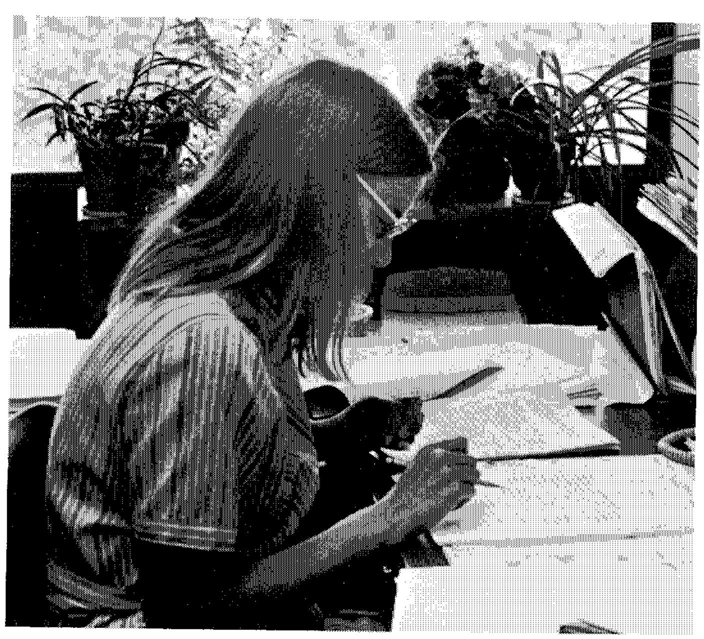
****Deceased 10 March 1984

Executive Committee

Investment Committee

Audit Committee

Judy Kleindinst figures a budget.



Shelley Lauzon

1983 Sources of Support for Research and Education

ALCOA Foundation
Alden Electronic & Impulse Recording Equipment Company, Inc.
Aluminum Company of America
Amoco Foundation, Inc.
Amoco Production Company
Associates & Corporation Members of the Woods Hole Oceanographic Institution
Atlantic Richfield Company
Avon Products Foundation, Inc.
Babylon Tuna Club
Benthos, Inc.
Bio-Diesel of Burlington
Cabot Corporation Foundation, Inc.
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Chevron, U. S. A.
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Conoco, Inc.
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Estate of Henry A. Gilbert
Gulf Oil Corporation
Gulf Oil Foundation
Gulf States Utilities Company
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Harbor Branch Foundation, Inc.
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International Business Machines Corporation
International Light Tackle Tournament Association
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R. K. Mellon Family Foundation
Millipore Corporation
The MITRE Corporation
Mobil Foundation, Inc.
Mobil Oil Corporation
The Ambrose Monell Foundation
Monsanto Fund
National Geographic Society
New England Electric System
New England Farm and Garden Association, Inc.
New England Power Company
New England Power Service Company
Norton Company Foundation, Inc.
Ocean City Light Tackle Club
Ocean City Marlin Club, Inc.
Oceaneering International, Inc.
Olin Corporation Charitable Trust
Pennwalt Corporation
Pew Memorial Trust
Phelps Dodge Foundation
Phillips Petroleum
Henry B. Plant Memorial Fund
Pneumo Foundation
Port Aransas Rod and Reel Club
PPG Industries Foundation
PSE&G Research Corporation
Raytheon Company
Riegel Textile Corporation Foundation
Rockwell International Corporation
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Sailfish Club of Florida
Shawmut Bank of Cape Cod
Shell Development Company
Shell Internationale Petroleum
Shell Oil Company
Francis P. Shepard Foundation
Sippican Ocean Systems, Inc.
Sohio Petroleum Company
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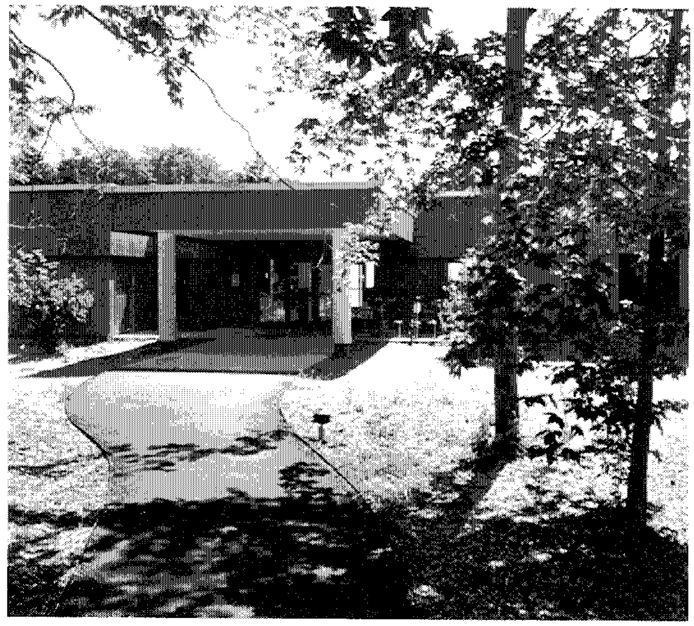


McLean Laboratory, Quissett Campus

Sun Exploration and Production Company
Texaco, Inc.
Texaco Philanthropic Foundation, Inc.
The Textron Charitable Trust
Textron, Inc.
Time, Inc.
Union Oil Company of California
Union Oil Company of California Foundation
United States Government
- Department of Agriculture
- Department of Commerce
  - National Oceanic and Atmospheric Administration
  - National Marine Fisheries Service
  - National Sea Grant Program
- Department of Defense
  - Department of the Army
  - Department of the Air Force
  - Department of the Navy
    - Office of Naval Research
  - Department of Energy
  - Environmental Protection Agency
  - Department of the Interior
    - U.S. Geological Survey
  - National Aeronautics & Space Administration
  - National Institute of Health
  - National Science Foundation
  - Department of State

United States Steel Foundation, Inc.
The George R. Wallace Foundation
Dr. Stanley W. Watson
Edwin S. Webster Foundation
Westcott Construction Company
West Point-Pepperell Foundation, Inc.

Financial Statements

Highlights

The Institution's total operating revenue increased 21% in 1983 to $46,351,069 compared with a 1% increase and total revenue in 1982 of $38,318,740. Excess current unrestricted funds of $1,000,000 were transferred to Unexpended Plant Funds.

Funding for Sponsored Programs increased 24% in 1983 as compared to 1982. The increase results partly from continued strong funding from the National Science Foundation which increased from $16,721,000 in 1982 to $19,978,000 in 1983, an increase of 19%. Included in the increase was $668,000 for partial support for installation of a new A-frame for the R/V *Atlantis II*. The 47% increase in Office of Naval Research funding from $7,808,000 in 1982 to $11,511,000 in 1983 was due primarily to significant increases in support for the Deep Submergence Laboratory, Acoustic Tomography, and the Buoy Program as well as the remaining support of $594,000 for the *Atlantis II* A-frame. Following is a list of funding sources for Sponsored Programs:

	1983	*1982*	*Increase (Decrease)*
National Science Foundation:			
Science Projects	$11,885,000	$10,300,000	15.4%
Facilities Projects	8,093,000	6,421,000	26.0%
Office of Naval Research	11,511,000	7,808,000	47.4%
Department of Energy	812,000	701,000	15.8%
National Oceanic & Atmospheric Administration	1,869,000	1,735,000	7.7%
Other Government	1,819,000	2,033,000	(10.5%)
Restricted Endowment Income	685,000	457,000	49.9%
Other Restricted Gifts, Grants and Contracts	4,262,000	3,600,000	18.4%
	$40,936,000	$33,055,000	23.8%

Capital expenditures were $2,241,000 in 1983, a 23% increase over 1982 expenditures of $1,816,000. Funds were expended to complete the Paul M. Fye Laboratory, to construct warehouse space, and for our continuing program of equipment replacement, especially in the area of computer resources. Funds for capital improvements were derived from gifts, depreciation recovery, and use of other Institution unrestricted income.

	1983	*1982*	
Other statistics of interest are:			
Full-time Equivalent Employees	772	800	(3.5%)
Total Compensation (including overtime and benefits)	$23,620,000	$21,269,000	11.1%
Retirement Trust Contribution	2,184,000	1,932,000	13.0%
Endowment Income (net)	2,634,000	2,969,000	(11.3%)
Additions to Endowment Principal	791,000	147,000	438.1%
Endowment Principal (year-end at market value)	57,473,000	52,793,000	8.9%

Gifts and grants from private sources including the 1,449 WHOI Associates totaled $2,860,000 in 1983, of which $2,201,000 was restricted and $659,000 was unrestricted as follows:

Addition to Endowment Principal	$ 327,000
Laboratory Construction	684,000
Marine Policy & Ocean Management	458,000
Ocean Engineering Research Center	150,000
Benthonic Foraminifera Studies	123,000
Education Program	21,000
Center for Analysis of Marine Systems	126,000
Coastal Research Programs	250,000
Other Research Programs	62,000
Unrestricted	659,000
	$2,860,000

Funds availed of in support of the Education Program were derived principally from endowment income received in 1983 totalling $1,325,000. In addition to other funds restricted for education, unrestricted funds of $381,000 were availed of for the Education Program. Research contracts and grants provided student support in the amount of $666,000.

Your attention is invited to the Financial Statements and the notes accompanying them, audited by Coopers & Lybrand.

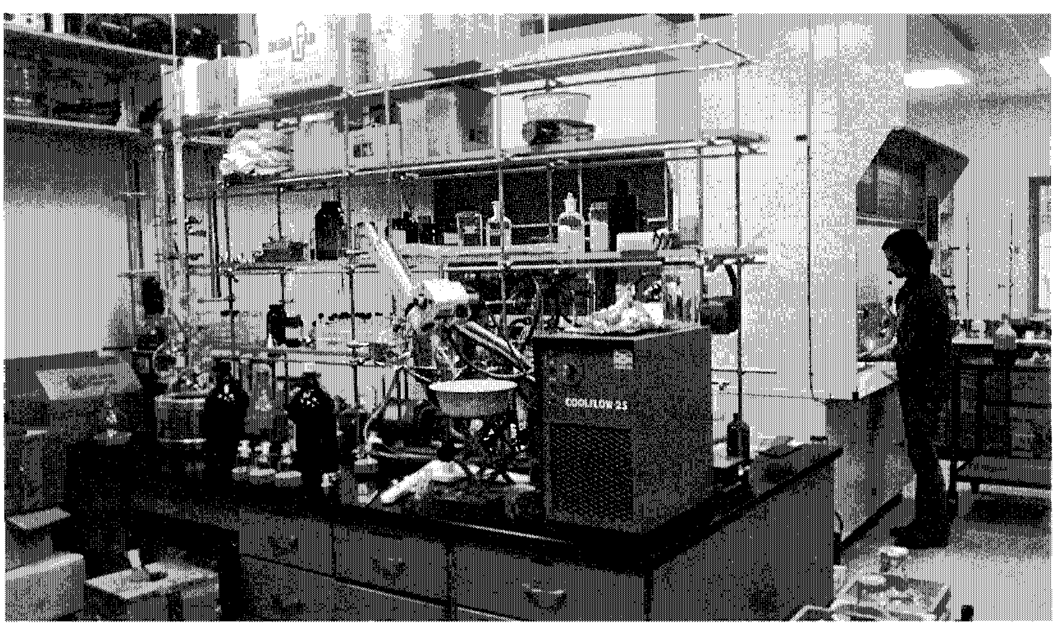
Joseph Kiebala, Jr.
Assistant Director for Finance and Administration
Kenneth S. Safe, Jr.
Treasurer
Gary B. Walker
Controller

Balance Sheets, December 31, 1983 and 1982

ASSETS	1983	1982
Current Fund Assets (Note A):		
Cash	$ (136,327)	$ (206,598)
Short-term investments, at cost which approximates market	11,837,079	9,815,000
Accrued interest	106,587	50,981
Reimbursable costs and fees:		
Billed	423,347	773,076
Unbilled	631,902	344,955
Other receivables	380,888	123,503
Inventories	449,106	594,770
Deferred charges and prepaid expenses	91,468	76,140
Deferred fixed rate variances	164,431	1,572,330
Due (to)/from other funds	(4,247,263)	(4,011,319)
	9,701,218	**9,132,838**
Endowment and Similar Fund Assets (Notes A and B):		
Investments, at market:		
Bonds	18,072,639	15,361,934
Stocks	35,743,528	33,339,147
Other	113,720	110,944
Total investments (cost $45,463,470 in 1983 and $37,864,530 in 1982)	53,929,887	48,812,025
Cash and cash equivalents	3,543,605	3,960,444
Due (to)/from current fund	–	20,050
	57,473,492	**52,792,519**
Annuity Fund Assets (Note A):		
Investments, at market (cost $67,951 in 1983 and $67,255 in 1982)	102,700	97,280
Cash	1,928	2,718
	104,628	**99,998**
Plant Fund Assets:		
Land, buildings, and improvements	21,840,140	18,914,176
Vessels and dock facilities	7,420,676	7,363,584
Laboratory and other equipment	3,703,389	3,441,500
Construction in progress	23,665	1,065,112
	32,987,870	30,784,372
Less accumulated depreciation	11,724,960	10,687,476
	21,262,910	20,096,896
Due from current fund	4,247,263	3,991,269
	25,510,173	**24,088,165**
	$92,789,511	**$86,113,520**

LIABILITIES AND FUND BALANCES	1983	1982
Current Fund Liabilities and Balances:		
Accounts payable, other accrued expenses and deferred revenues	$ 1,936,298	$ 1,142,157
Accrued payroll related liabilities	1,923,641	1,549,298
Unexpended balances restricted for:		
Sponsored Research	1,713,233	1,978,008
Education Program	384,316	581,329
Total restricted balances	2,097,549	2,559,337
Unrestricted balances designated for:		
Income and salary stabilization	2,949,998	2,733,720
Ocean industry program	273,177	289,064
Unrestricted current fund	520,555	543,619
Fiftieth anniversary fund	–	315,643
Total unrestricted balances	3,743,730	3,882,046
	9,701,218	**9,132,838**
Endowment and Similar Fund Liabilities and Balances:		
Endowment:		
Income restricted	35,003,586	31,887,114
Income unrestricted	651,782	588,484
Term endowment	3,700,359	3,446,156
Quasi-endowment:		
Income restricted	8,353,700	7,771,385
Income unrestricted	9,764,065	9,099,380
	57,473,492	**52,792,519**
Annuity Fund Liabilities and Balance:		
Annuities payable	23,381	24,406
Fund balance	81,247	75,592
	104,628	**99,998**
Plant Fund Balances:		
Invested in plant	21,262,910	20,096,896
Unexpended, unrestricted	4,247,263	3,991,269
	25,510,173	**24,088,165**
	$92,789,511	**$86,113,520**

The accompanying notes are an integral part of the financial statements.



Shelley Lauzon

Chemistry laboratory in the Fye Laboratory.

Statement of Current Fund Revenues, Expenses and Transfers for the years ended December 31, 1983 and 1982

Revenues	**1983**	**1982**
Sponsored Research:		
Government	$ 35,988,942	$ 28,997,875
Nongovernment	4,946,970	4,057,523
	40,935,912	33,055,398
Education funds availed of	1,720,821	1,543,083
Total restricted	42,656,733	34,598,481
Unrestricted:		
Fees	484,334	329,532
Endowment and similar fund income	648,833	739,657
Gifts	659,089	743,158
Tuition	645,523	515,884
Investment income	764,853	954,900
Oceanus subscriptions	244,157	203,618
Other	247,547	233,510
Total unrestricted	3,694,336	3,720,259
Total revenues	**46,351,069**	**38,318,740**
Expenses and Transfers		
Sponsored research:		
Salaries and fringe benefits	11,913,384	10,664,731
Ships and submersibles	7,370,509	5,711,909
Materials and equipment	5,581,783	4,794,727
Subcontracts	854,341	1,475,814
Laboratory costs	3,463,170	2,539,980
Other	7,589,201	4,681,775
General and administrative	4,163,524	3,186,462
	40,935,912	33,055,398
Education:		
Faculty expense	421,188	385,819
Student expense	861,555	773,395
Postdoctoral programs	319,618	286,380
Other	214,022	185,018
General and administrative	285,417	217,924
	2,101,800	1,848,536
Unsponsored research	918,858	550,966
Oceanus magazine	292,507	261,874
Other activities	544,595	590,809
General and administrative	231,522	132,432
	1,987,482	1,536,081
Total expenses	**45,025,194**	**36,440,015**
Net increase-unrestricted current fund	**$ 1,325,875**	**$ 1,878,725**
Designated for:		
Income and salary stabilization	$ 216,278	$ 246,552
Ocean industry program	(15,887)	24,267
Unrestricted current fund	66,490	88,972
Fiftieth anniversary fund	–	154,666
Innovative research fund	–	153,936
Endowment fund	58,994	10,332
Plant fund, unexpended	1,000,000	1,200,000
Total	**$ 1,325,875**	**$ 1,878,725**

The accompanying notes are an integral part of the financial statements.

Report of the Certified Public Accountants

To the Board of Trustees of Woods Hole Oceanographic Institution:

We have examined the balance sheets of Woods Hole Oceanographic Institution as of December 31, 1983, and 1982, and the related statements of changes in fund balances, and of current fund revenues, expenses and transfers for the years then ended. Our examinations were made in accordance with generally accepted auditing standards and, accordingly, included such tests of the accounting records and such other auditing procedures as we considered necessary in the circumstances.

In our opinion, the financial statements referred to above present fairly the financial position of Woods Hole Oceanographic Institution as of December 31, 1983, and 1982, the changes in its fund balances, and its current fund revenues, expenses and transfers for the years then ended, in conformity with generally accepted accounting principles applied on a consistent basis.

Coopers & Lybrand

Boston, Massachusetts
March 27, 1984

Statement of Changes in Fund Balances for the years ended December 31, 1983 and 1982

1983	Current Fund: Restricted	Current Fund: Unrestricted	Current Fund: Total	Endowment and Similar Funds	Annuity Funds	Plant Fund: Invested In Plant	Plant Fund: Unexpended	Total Funds
Increases:								
Gifts, grants and contracts:								
Government	$35,775,134		$35,775,134					$35,775,134
Nongovernment	4,362,960	$ 659,089	5,022,049	$ 326,496			$ 683,625	6,032,170
Endowment and similar funds investment income (Note D)	1,985,502	648,833	2,634,335					2,634,335
Net increase in realized and unrealized appreciation				3,889,689				3,889,689
Other	71,946	2,386,414	2,458,360		$ 5,655			2,464,015
Total increases	42,195,542	3,694,336	45,889,878	4,216,185	5,655		683,625	50,795,343
Decreases:								
Expenditures	(42,656,733)	(2,368,461)	(45,025,194)					(45,025,194)
Depreciation (Note A)						$(1,099,057)	837,243	(261,814)
Other						197		197
Total decreases	(42,656,733)	(2,368,461)	(45,025,194)			(1,098,860)	837,243	(45,286,811)
Net change before transfers	(461,191)	1,325,875	864,684	4,216,185	5,655	(1,098,860)	1,520,868	5,508,532
Transfers – additions (deductions):								
Current revenues to plant fund		(1,000,000)	(1,000,000)				1,000,000	–
Current revenues to endowment	(597)	(148,548)	(149,145)	149,145				–
Fiftieth anniversary fund to endowment		(315,643)	(315,643)	315,643				–
Plant asset additions						2,264,874	(2,264,874)	–
Total transfers	(597)	(1,464,191)	(1,464,788)	464,788		2,264,874	(1,264,874)	–
Change in fund balance for the year	(461,788)	(138,316)	(600,104)	4,680,973	5,655	1,166,014	255,994	5,508,532
Fund balance, December 31, 1982	2,559,337	3,882,046	6,441,383	52,792,519	75,592	20,096,896	3,991,269	83,397,659
Fund balance, December 31, 1983	**$ 2,097,549**	**$3,743,730**	**$ 5,841,279**	**$57,473,492**	**$81,247**	**$21,262,910**	**$4,247,263**	**$88,906,191**

1982	Current Fund: Restricted	Current Fund: Unrestricted	Current Fund: Total	Endowment and Similar Funds	Annuity Funds	Plant Fund: Invested In Plant	Plant Fund: Unexpended	Total Funds
Increases:								
Gifts, grants and contracts:								
Government	$28,690,477		$28,690,477					$28,690,477
Nongovernment	3,715,232	$ 743,158	4,458,390	$ 136,359			$ 134,751	4,729,500
Endowment and similar funds investment income (note D)	2,228,882	739,657	2,968,539					2,968,539
Net increase in realized and unrealized appreciation				10,273,911				10,273,911
Other	78,334	2,237,443	2,315,777		$15,422			2,331,199
Total increases	34,712,925	3,720,258	38,433,183	10,410,270	15,422		134,751	48,993,626
Decreases:								
Expenditures	(34,598,481)	(1,841,534)	(36,440,015)					(36,440,015)
Depreciation (Note A)						$(1,001,179)	739,365	(261,814)
Other	(105,514)		(105,514)			(346)		(105,860)
Total decreases	(34,703,995)	(1,841,534)	(36,545,529)			(1,001, 525)	739,365	(36,807,689)
Net change before transfers	8,930	1,878,724	1,887,654	10,410,270	15,422	(1,001,525)	874,116	12,185,937
Transfers – additions (deductions):								
Current revenues to plant fund		(1,200,000)	(1,200,000)				1,200,000	–
Current revenues to endowment	(641)	(10,332)	(10,973)	10,973				–
Current revenues to innovative research fund	153,935	(153,935)						–
Plant asset additions						1,771,137	(1,771,137)	–
Other						(986)	986	–
Total transfers	153,294	(1,364,267)	(1,210,973)	10,973		1,770,151	(570,151)	–
Change in fund balance for the year	162,224	514,457	676,681	10,421,243	15,422	768,626	303,965	12,185,937
Fund balance, December 31, 1981	2,397,113	3,367,589	5,764,702	42,371,276	60,170	19,328,270	3,687,304	71,211,722
Fund balance, December 31, 1982	**$ 2,559,337**	**$3,882,046**	**$ 6,441,383**	**$52,792,519**	**$75,592**	**$20,096,896**	**$3,991,269**	**$83,397,659**

The accompanying notes are an integral part of the financial statements.

Notes to Financial Statements

A. Summary of Significant Accounting Policies:

Fund Accounting

In order to comply with the internal designations and external restrictions placed on the use of the resources available to the Institution, the accounts are maintained in accordance with the principles of fund accounting. This procedure classifies resources into various funds in accordance with their specified activities or objectives.

Investments

Investments in securities are stated at market value determined as follows: securities traded on a national securities exchange are valued at the last reported sales price on the last business day of the year; securities traded in the over-the-counter market and listed securities for which no sales prices were reported on that day are valued at closing bid prices. Investments for which a readily determinable market value cannot be established are stated at a nominal value of $1; income from such investments is not significant.

Income, net of investment expenses, is distributed on the unit method. Unrestricted investment income is recognized as revenue when received and restricted investment income is recognized as revenue when it is expended for its stated purpose. Realized and unrealized gains and losses are attributed to the principal balance of the funds involved.

The Institution follows the accrual basis of accounting except that endowment and similar fund investment income is recorded on a cash basis. The difference between such basis and the accrual basis does not have a material effect on the determination of investment income earned on a year-to-year basis.

Contracts and Grants

Revenues associated with contracts and grants are recognized as related costs are incurred. Beginning with fiscal 1978, the Institution has negotiated with the government fixed rates for the recovery of certain indirect costs. Such recoveries are subject to carryforward provisions that provide for an adjustment to be included in the negotiation of future fixed rates.

Gifts

Gifts are recorded in the applicable funds when received. Noncash gifts are generally recorded at market value on the date of gift although certain noncash gifts for which a readily determinable market value cannot be established are recorded at a nominal value of $1 until such time as the value becomes known. Unrestricted gifts are recognized as revenue when received and restricted gifts are recognized as revenue as they are expended for their stated purposes.

Plant

Plant assets are stated at cost. Depreciation is provided at annual rates of 2% to 5% on buildings, 3⅓% on Atlantis II and 5% to 33⅓% on equipment. Depreciation expense on Institution-purchased plant assets amounting to $837,243 in 1983 and $739,365 in 1982 has been charged to operating expenses. Depreciation on certain government funded facilities (Atlantis II, Laboratory for Marine Science and the dock facility, amounting to $261,814 in each year) is accounted for as a direct reduction of the plant asset and invested in plant fund. Title to the research vessel Atlantis II is contingent upon its continued use for oceanographic research.

The Institution consolidates available cash from the plant fund with other cash in the current fund for investment.

Annuity Funds

On the date of receipt of annuity fund gifts, the actuarially computed value of the future payments to annuitants is recorded as a liability and any excess amount of the gift is credited to the fund balance. The actuarial values of the liabilities are recomputed annually.

Reclassification of 1982 Balances

Certain balances in the 1982 financial statements have been reclassified to conform with the 1983 presentation.

B. Endowment and Similar Fund Investments:

The cost and market value of investments held at December 31, 1983, and 1982, are as follows:

	December 31, 1983 Cost	December 31, 1983 Market	December 31, 1982 Cost	December 31, 1982 Market
Government and government agencies	$ 14,405,246	$ 14,692,093	$ 12,188,174	$ 13,482,335
Convertible bonds	786,563	745,250	200,500	196,375
Corporate bonds	2,533,246	2,635,296	1,540,047	1,683,224
Convertible preferred stocks	596,790	496,000	–	–
Common stocks	27,041,625	35,247,528	23,835,809	33,339,147
Fiduciary Trust Co. Fund	100,000	113,720	100,000	110,944
Total investments	**$45,463,470**	**$53,929,887**	**$37,864,530**	**$48,812,025**

C. Pooled Investment Units:

The value of an investment unit at December 31, 1983, and 1982, was $1.2896 and 1.2011 respectively. The investment income per unit for 1983 and 1982 was $.0594 and .0677 respectively.

	1983	1982
Unit value beginning of year	$ 1.2011	$ .9672
Unit value end of year	1.2896	1.2011
Net change for the year	.0885	.2339
Investment income per unit for the year	.0594	.0677
Total return per unit	**$ .1479**	**$.3016**

D. Endowment and Similar Fund Income:

Income of endowment and similar funds consisted of the following:

	1983	1982
Dividends	$ 888,367	$ 710,187
Interest	2,074,335	2,513,261
Other	–	2,994
	2,962,702	3,226,442
Investment management costs	(328,367)	(257,903)
Net investment income	**$2,634,335**	**$2,968,539**

E. Retirement Plan:

The Institution has a noncontributory defined benefit trusteed retirement plan covering substantially all full-time employees. The Institution's policy is to fund pension cost accrued which includes amortization of prior service costs over a 30-year period. Retirement plan costs charged to operating expense amounted to $2,352,000 in 1983 and $2,072,000 in 1982, including $168,000 and $140,000, respectively, relating to expenses of the retirement trust. As of January 1, 1983 (the most recent valuation date) the comparison of accumulated plan benefits and plan net assets is as follows:

	January 1 1983	January 1 1982
Actuarial present value of accumulated plan benefits:		
Vested	$ 19,282,937	$ 16,977,517
Nonvested	1,032,504	954,693
Total actuarial present value of accumulated plan benefits	$20,315,441	$17,932,210
Net assets available for plan benefits	**$25,435,384**	**$19,202,572**

The assumed rate of return used in determining the actuarial present value of accumulated plan benefits was six and one-half percent compounded annually.

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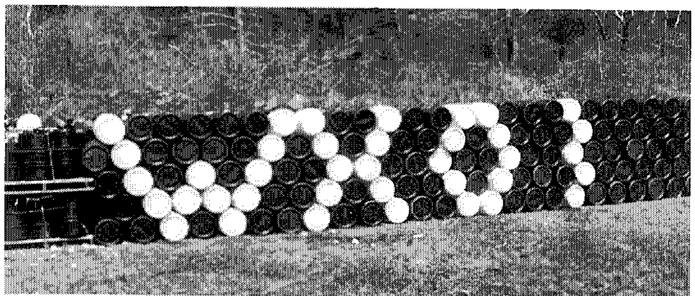
Sea smoke rises from Great Harbor beyond the *Atlantis II.*



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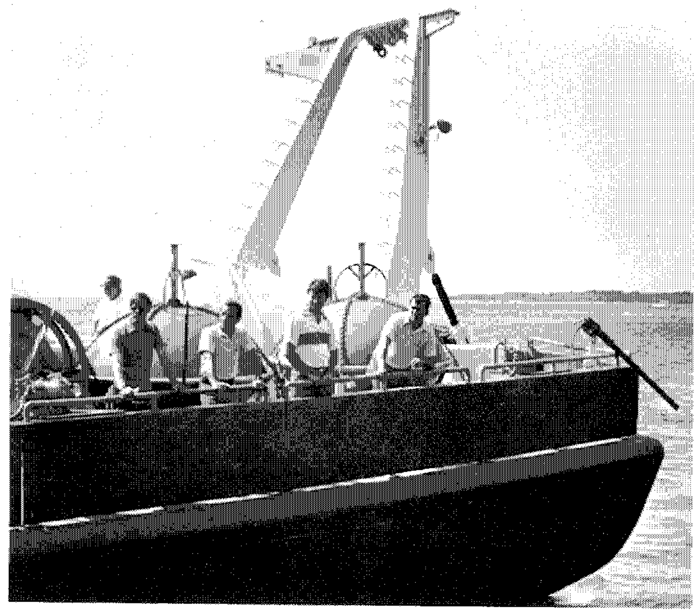
Above: Colored water containers imaginatively arranged behind Clark Laboratory by the Building Services Group. Top right: *Oceanus* departs for an acoustic tomography cruise. Bottom right: Eben Franks uses liquid nitrogen in the mass spectrometer in McLean Laboratory. Below: Chris Dunn (bottom) instructs Tom Bolmer in placement of instruments on a BASS tripod.



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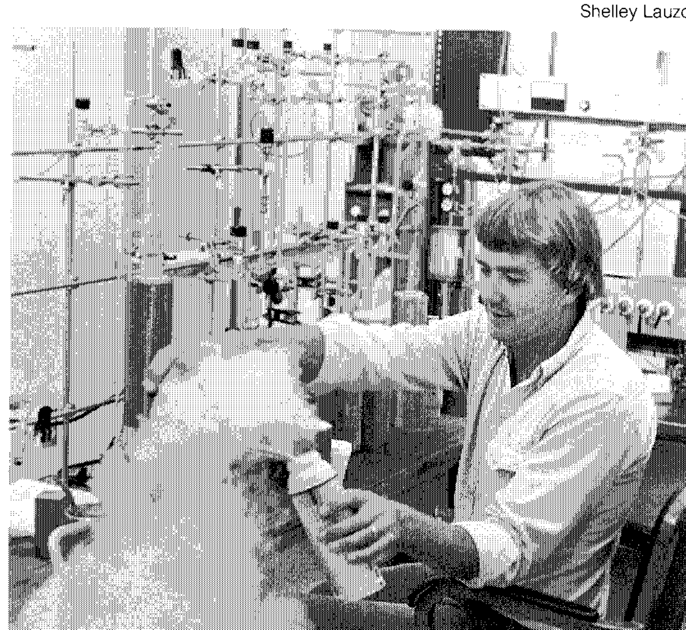

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